SSERVI-ESF14-001

Author: MICHAEL BUSCH

ORAL

Asteroid Population Characterization

Radar and Near-Earth Asteroid Exploration Missions

Ground-based radar observations provide information on the trajectories, shapes, spin states, and surface structure of near-Earth asteroids in advance of spacecraft missions. This is crucial for mission planning and for reducing mission risks. I will illustrate this with two examples: 4179 Toutatis, target of a flyby by the Chang'e 2 spacecraft; and 2008 EV5 (hereafter EV5), which has been proposed variously as a target for ESA's MarcoPolo R mission, one version of the Asteroid Retrieval Mission, and a deep-space human asteroid mission.Toutatis is near to a 4:1 orbital resonance with Earth, and makes sets of close Earth approaches separated by several decades. It was observed briefly during the previous set of close approaches in the 1930s, discovered after the first flyby in the most recent set in 1988, and was observed with radar using the Goldstone and Arecibo facilities at 4 year intervals between 1992 and 2012. The radar observations show that Toutatis is elongated, bifurcated, and has a complicated non-principal-axis spin state dramatically altered by tidal torques from the Earth and Sun. The radar astrometry and spin-state model allowed Chang'e 2 to make an exceptionally close flyby of the asteroid in 2012, passing within 1 km of Toutatis' surface.EV5 was observed with optical, infrared, and radar techniques during its most recent close Earth approach in 2008. The radar images showed that EV5 is a ~400 m spheroid, with an equator-aligned ridge broken by at ~150 m concavity. It has several ~10-m boulders, or at least exposed high-standing and well-defined blocks, on its surface. EV5 will be readily accessible by spacecraft in the early-to-mid 2020s, and so has been proposed as the target for several different missions. ESA's MarcoPolo R mission proposed to go to EV5, retrieve samples from its surface, and return them to Earth; ESA has elected to not pursue MarcoPolo R at this time. One version of NASA's proposed Asteroid Retrieval Mission would go to EV5, remove a boulder from its surface, and return that boulder to a distant lunar orbit for use by astronauts. And EV5 has also been considered as a target for deep-space human missions, with opportunities for a yearlong mission spending two months at the asteroid.Radar reconnaissance of other near-Earth asteroids provides a broad selection of well-characterized targets to choose from for future exploration.

SSERVI-ESF14-002

Author: HUMBERTO CAMPINS

ORAL

Asteroid Population Characterization

Water and Organic Molecules on Asteroids and on Earth

The detection of water ice and organic molecules on of asteroids 24 Themis and 65 Cybele were reported in 2010 and 2011, respectively. Infrared spectra of these asteroids indicate that the ice and organics are widespread on their surfaces. In addition, water vapor was recently discovered emanating from asteroid 1 Ceres. These discoveries have important implications on current views of primitive asteroids, the dynamics of the early Solar System, and the delivery of water and organic molecules to Earth. They are also relevant to several space missions, including Dawn, Gaia, Hayabusa 2, OSIRIS-REx and WISE.

SSERVI-ESF14-003

Author: MARTIN CONNORS

ORAL

Asteroid Population Characterization

The Temporal Variation of the Rate of Interplanetary Field enhancements seen in Association with Asteroids 2201 Oljato at Venus and 138175 at Earth: Evidence for Co-orbital Material Disturbed by Gravitational Interactions

We have modeled the orbital evolution of material liberated from both 2201 Oljato and asteroid 138175 in an attempt to understand the temporal changes associated with IFEs. These IFEs are seen when the asteroidal orbits are inside the orbit of the detecting satellite and the observation is close to the ascending and descending nodes so that collisions with the co-orbiting debris could cause detectable charged dust clouds carried outward by the solar wind across our satellites in the ecliptic plane. These simulations show that the co-orbiting debris trail is disrupted by passages near the Earth and Venus. Gaps induced in the trail can result in seeming temporal changes as it is sampled at varying places relative to the source body. On a longer time scale, the debris spreads along the orbit and is mainly detected surrounding one or both of the body's nodes after inferred secondary collisions. The gap production mechanism is operative for a large range of ejection speeds, and is absent in a control case without close encounters.

Author: THOMAS EUBANKS

ORAL

Asteroid Population Characterization

Asteroid Radio Tomography : Looking Inside Small Bodies at 10 meter wavelengths.

Asteroid mining will require evaluation not only of the surface geology of a candidate asteroid, but ideally also a view of the interior of the body. This ability is important for either mission concept currently under consideration for the NASA Asteroid Retrieval Mission (ARM), and also for asteroid prospecting (the evaluation of asteroids as mining candidates). It should be possible to use 10 - 40 MegaHertz (MHz) radio waves to observe completely through the interior of many types of small (< 100 meter diameter) Near Earth Objects (NEO), as the MARSIS (1.3 - 5 MHz) and SHARAD (15 - 25 MHz) radar systems in orbit around Mars, which have demonstrated the ability for ground penetrating radar to image many 100's of meters underneath the Martian surface. These radars, however, have horizontal resolutions of 100's of meters based on aperture (delay-Doppler) synthesis using the ~ 2 km / sec orbital velocity of a Mars satellite. In addition an orbiting radar is ~ 300 km from the Martian surface, which both requires a fairly powerful radar (SHARAD, for example, is a 10 W radar) and, with ~ 2 msec Round Trip Time (RTT) for radar pulses, allows for a temporal separation of transmit and receive windows (SHARAD uses a 85 microsecond transmit chirp and a 135 microsecond receive window). The physics of radio tomography of small NEO is almost entirely different from the Martian case. The current ARM mission plan intends for an examination of a target NEO at ~ 1 km, at which distance the spacecraft stationkeeping velocity is negligible (orbital velocities of a small NEO at 1 km are of order 1 cm / sec), RTTs are of order a few microseconds, and the entire asteroid is of a size comparable to the first Fresnel zone at 30 MHz (implying that diffraction cannot be ignored for these small bodies). In addition, for both ARM and for asteroid prospecting the mass and power consumption of radio systems would be severely constrained. This talk will describe the principles of Asteroid Radio Tomography (ART). While ART could potentially use both active radar, the Jupiter-Io decametric S-bursts are an interesting possible radio source for ART. These bursts are predictable, circularly polarized, very strong (~105 Janskies as seen from a NEO orbit), naturally chirped in frequency, and very coherent, with brightness temperatures > 1010 K. A 10 meter helical radio antenna being designed for the Solar Scout mission would have a 30 MHz sensitivity of 500 Janskies or better, and could potentially observe these Jupiter bursts completely through a 100 meter rubble-pile type asteroid. The ability to forgo the mass and power consumption of a radar transmitter would have, of course, numerous benefits, and this technique should be considered for future asteroid missions.

SSERVI-ESF14-005

Author: MOHAMED THARWAT HEIKAL

ORAL

Asteroid Population Characterization

Major Global Changes and their Impact Effects

Major global changes would result from the impact of a large meteorites, asteroids or comets. The collision would set the planet ringing like a giant bell. This leads to produce powerful earthquakes and violent volcanic eruptions. In addition, the impact into the ocean would send gigantic tsunami racing toward nearby shores. The impact could also reverse the planet's magnetic field.On the other hand, the impact effects would make a thick blanket of dust into the atmosphere, shutting out the Sun and chilling the planet. The dust and smoke blocking out the Sun would cause a rapid cooling of Earth's surface by 20oC or more. The cooling would persist from several months, bringing freezing weather conditions, giving rise to glacial accumulation. So much damage would beset Earth that extension of species would surely follow.Keywords: Global changes, meteorites, dust storms, earthquakes and volcanic activity, tsunami, magnetic fields, glaciations, mass extinction

Author: GENNADY KOCHEMASOV
POSTER

Asteroid Population Characterization

Orbital energy and self-breaking asteroids

The classical planetology considers impacts as a main source of energy reworking celestial bodies. However a region or regions of impacting objects affecting all planetary bodies in the Solar system is poorly understood. But now planetologists have several tens of images of full discs of these bodies. Distribution patterns of "impact traces" – craters in many of them are surprisingly regular. They show alignments, regular grids not related to random hits expected from impacts but rather require more regular and ubiquitous structuring force. Moreover, such regular patterns appear in the outer gaseous spheres of some bodies including the Sun's photosphere. It was shown earlier [Kochemasov, 1995-2013] that such regular patterns appear due to warping action of inertia-gravity waves affecting all bodies moving in keplerian elliptical orbits. Periodically changing accelerations of celestial bodies cause their wave warping having in rotating bodies four ortho- and diagonal directions. An interference of 4 directions of standing waves brings about a regular net of uprising, subsiding and neutral tectonic blocks. Naturally polygonal in details they appear as rings in cosmic images. This is one of reasons why they are often confused with round impact craters and essentially disfigure their statistics. A fundamental nature of the wave woven nets of even sized round "craters" (granules) is dependence of their sizes on orbital frequencies of bodies. The lower frequency the larger sizes, the higher frequency the smaller granule sizes. Compare 6 bodies with differing orbital frequencies, granule sizes, radii, and compositions: Titan (radius, R 2913 km, orbital frequency 1/15.9 days, granule diameter πR/91), Callisto (2445, 1/16.7; πR/88), Moon (1738, 1/27.3; πR/48), Mercury (2440, 1/88; πR/16), Earth (6378,1/365, πR/4), Mars (3397,1/687, πR/2). Images of their discs "peppered" with round features diameters of which precisely correspond to their orbital frequencies witness that such tectonic patterns can originate due to orbital energies. "Orbits make structures" – this short notion adequately reflects the expressed above observations. The existing correspondence between orbital frequencies and tectonic granulations proving the structuring role of orbital energy was earlier noted in comparative planetology of the terrestrial planets. The row of Mercury, Venus, Earth, Mars, asteroids with decreasing orbital frequencies is remarkable by increasing relative sizes of tectonic granules, relief ranges, iron content in lowland basalts and decreasing atmospheric masses from Venus to Mars. In this spectacular row the position of asteroids is especially remarkable. The strongest amplitude fundamental wave1 embraces an asteroid body making it strongly bent. Its extended convex hemisphere is deeply cracked and the concave one from the opposite site approaches the deepest fissures. As a result the body disintegrates and two or several pieces move as binaries, polycomponent asteroids, asteroids with satellites. Dumb-bells shapes often are observed. Examples of various stages of destruction are asteroids Eros, Toutatis, Braille, Castalia, Hector, and recently observed P/2013R3 that shows enormous volumes of gas-dust clouds accompanying the process. The orbiting clouds in the past may have been a media for gravity separation of M-, S-, and C-asteroids.

SSERVI-ESF14-007

Author: SAMUEL LAWRENCE

POSTER

Asteroid Population Characterization

Mineralogical Determinations of Meteorites and Asteroids Using Hapke Models

Asteroid surfaces spectral properties are controlled by asteroid regolith characteristics, including mineralogy, particle size, impact-produced glass, and the degree of space weathering. We updated an existing model designed to facilitate convenient spectral interpretation of V- and S-type asteroids [1,2]. Our model is based upon the works of Hapke [3–5], which demonstrated how visible/near-infrared spectra of mineral mixtures could be computed from optical constants at arbitrary grain sizes and abundances. Our new model leverages recent advances in Hapke modeling, including new optical constants for pyroxene and olivine [6,7] and Fe,Ni-metal [8]. Our approach is to populate a lookup table (LUT) with forward-modeled spectra encapsulating the plausible spectral-compositional parameter space for asteroids. We use a "grid search" (where the closest LUT match to the unknown is determined, with the 1 _m and 2 _m band center position incorporated as a weighting factor) to extract estimates of the mineral modes and composition of the unknown spectrum. This approach has been tested using lunar materials [6,9], but has not yet been validated for the asteroids using meteorites. To do so, we compared the outputs of our mineral extraction algorithm to 43 meteorite spectra where the spectral properties, mineral chemistry, and modes have been well-determined [10–16]. Our approach produced estimates of the modal mineralogy that were consistently accurate to at least within 15 volume % of the experimentally-determined meteorite mineral mode. Our approach is more sensitive to basaltic achondrite compositions (median modal mineralogical divergence: 1.5 vol %) than ordinary chondrites (median modal mineralogical divergence: 7 volume %). We extracted a mineralogy estimate for asteroid 25143 Itokawa, obtaining a modal mineralogy estimate completely consistent with the LL ordinary chondrite composition determined through analysis of the returned samples [17,18]. The capability provided by this Hapke-based approach towards the analysis of small body compositions represents a useful complement to existing methods of asteroid spectral interpretation.

Author: HONG-KYU MOON

POSTER

Asteroid Population Characterization

The DEEP-SOUTH: Round-the-clock Census of NEOs in the Southern Hemisphere

Korea Astronomy and Space Science Institute started a project to build a network of wide-field optical telescopes called the KMTNet (Korea Micro-lensing Telescope Network) in 2009. The KMTNet consists of three identical 1.6-m prime focus optics and 18K_18K mosaic CCD cameras that results in 2_2 degrees field of view with a delivered image quality less than 1.0 arcsec FWHM under atmospheric seeing of 0.75 arcsec. These telescopes will be located at CTIO in Chile, SAAO in South Africa, and SSO in Australia. This network of telescopes will be partly used for “Deep Ecliptic Patrol of the Southern Sky (DEEP-SOUTH)” as one of the secondary science projects. The three stations are longitudinally well separated, and hence will have a benefit of 24-hour continuous monitoring of the southern sky. The wide-field and round-the-clock operation capabilities of the facility are ideal for discovery and physical characterization of asteroids and comets. Based on time series observations with the KMTNet, orbits, absolute magnitudes (H), spin states, shapes and activity levels of asteroids and comets, including NEOs will be systematically investigated at the same time. Their approximate surface mineralogy will also be classified according to SDSS and Johnson Cousins BVRI colors. The first KMTNet telescope in CTIO will be put into operations in June 2014 and the whole network is expected to be on-line in late-2014. The KMTNet is expected to complement other surveys such as NEOWISE, by adding near-simultaneous visual-wavelength coverage, and extending the time-component of other discovery surveys in unique ways.

SSERVI-ESF14-009

Author: HONG-KYU MOON

ORAL

Asteroid Population Characterization

The DEEP-SOUTH: Round-the-clock Physical Characterization of NEOs in the Southern Hemisphere

Korea Astronomy and Space Science Institute started a project to build a network of wide-field optical telescopes called the KMTNet (Korea Micro-lensing Telescope Network) in 2009. The KMTNet consists of three identical 1.6-m prime focus optics and 18K_18K mosaic CCD cameras that results in 2_2 degrees field of view with a delivered image quality less than 1.0 arcsec FWHM under atmospheric seeing of 0.75 arcsec. These telescopes will be located at CTIO in Chile, SAAO in South Africa, and SSO in Australia. This network of telescopes will be partly used for "Deep Ecliptic Patrol of the Southern Sky (DEEP-SOUTH)" as a one of such secondary science projects. The three stations are longitudinally well separated, and hence will have a benefit of 24-hour continuous monitoring of the southern sky. The wide-field and round-the-clock operation capabilities of the facility are ideal for discovery and physical characterization of asteroids and comets. Based on time series observations with the KMTNet, orbits, absolute magnitudes (H), spin states, shapes and activity levels of asteroids and comets including NEOs will be systematically investigated at the same time. Their approximate surface mineralogy will also be discriminated using SDSS and Johnson Cousins BVRI colors. The first KMTNet telescope in CTIO will be put into operations in June 2014 and the whole network is expected to be on-line in late-2014.

Author: CAROLYN NUGENT

ORAL

Asteroid Population Characterization

Exploring asteroid surfaces: thermophysical modeling with NEOWISE observations

Thermophysical modeling, a technique that combines heat transfer calculations, infrared flux measurements, and a model of the physical shape of an asteroid, is used to measure the average surface thermal inertia on a body. A thermal inertia measurement can determine if an asteroid's surface is rocky or dusty, which has implications for the object's rotational and collisional history. Foreknowledge of surface composition assists the design of robotic or manned missions to asteroids. Additionally, thermal inertia measurements allow for more precise predictions of the strength of the Yarkovsky effect, a small non-gravitational force that measurably alters the orbits of some near-Earth asteroids. The NEOWISE mission, using the space-based Wide-Field Infrared Survey Explorer (WISE) telescope, observed over 158,000 minor planets, and produced a rich dataset for thermophysical modeling. We present measured thermal inertias derived by combining this dataset and radar-based asteroid shape models.Acknowledgements:This publication makes use of data products from the Wide-field Infrared Survey Explorer, which is a joint project of UCLA, and JPL/Caltech, funded by NASA. This publication also makes use of data products from NEOWISE, which is a project of JPL/Caltech, funded by the Planetary Science Division of NASA. C. Nugent is supported by a NASA Postdoctoral Program Fellowship, administered by Oak Ridge Associated Universities.

Author: ANDREAS PASEWALDT
POSTER

Asteroid Population Characterization

New Astrometric Observations of Phobos and Deimos with the SRC on Mars Express

Since early 2004 Mars Express (MEX) regularly performs approach maneuvers to the Martian moons (Jaumann et al. 2007, Oberst et al. 2008). During each approach the camera is directed to a fixed point on the celestial sphere, while Phobos or Deimos is crossing the field-of-view. A sequence of eight images is taken, of which the first and the last images are long time exposures to detect the faint light of background stars. Exposure times of the remaining images are adapted to the bright moon's surfaces.Given the position of the spacecraft (S/C) and the pointing of the camera, astrometric observations of the Martian moons can be derived from the SRC images (cf. Duxbury & Callahan 1988). These are the main input data of orbit models.Attitude and orbit data of the MEX S/C are provided by ESOC in the form of SPICE kernels. While the orbit data is reconstructed, the attitude information is only predicted. The camera pointing can be verified and improved by means of prediction and observation of background stars (Willner et al. 2008). For images showing no reference stars the pointing correction is interpolated assuming a linear pointing drift.Center-of-figure (COF) positions of Phobos and Deimos are determined by means of their shape models or control networks (Oberst et al. 2006, Willner et al. 2008). Based on theories of the satellite's orbit and rotation, image locations of limb or control points are predicted. Phobos' apparent limb has been derived by using the new 3-D shape model computed from HRSC and Viking Orbiter images (Willner et al. 2013). Limb or control points are recognized resp. identified and measured in the image. From corresponding pairs of predicted and observed limb or control points transformation parameters are derived that are applied on the predicted moon's COF.Line and sample of the satellite's COFs are corrected for pointing offsets and transformed to equatorial right ascension and declination coordinates in the International Celestial Reference Frame (ICRF). Weights of the observations are estimated as square root of sum of squares of uncertainties in S/C position, camera pointing and COF measurement. As result 121 pictures of Phobos and 136 pictures of Deimos have been reduced with accuracies between 0.5 and 3.6 km (1-_ error) (Pasewaldt et al. 2012).Duxbury, T.C., Callahan, J., 1988, Astronomy & Astrophysics, 201, 169; Jaumann, R., Neukum, G., Behnke, N., et al. 2007, Planetary and Space Science, 55, 928; Oberst, J., Matz, K.-D., Roatsch, T., et al. 2006, Astronomy & Astrophysics, 447, 1145; Oberst, J., Schwarz, G., Behnke, T., et al. 2008, Planetary and Space Science, 56, 473; Pasewaldt, A., Oberst, J., Willner, K., et al. 2012, Astronomy & Astrophysics, 545, A 144; Willner, K., Oberst, J., Waehlisch, M., et al. 2008, Astronomy & Astrophysics, 488, 361; Willner, K., Shi, X., Oberst, J., Planetary and Space Science, paper in press

Author: SUKRIT RANJAN

ORAL

Asteroid Population Characterization

How Many Low Delta-v Near-Earth Objects Remain Undiscovered?

The past decade has witnessed considerable growth of interest in missions to Near-Earth Objects (NEOs). NEOs are considered prime targets for human spaceflight initiatives (c.f. the Augustine report), and NASA has recently issued a Broad Agency Announcement soliciting proposals regarding developing technologies for asteroid retrieval. For-profit corporations such as Planetary Resources and Deep Space Industries aim to access and exploit NEOs for in-situ resource utilization including harvesting of water for propellant and life support and mining of high-value elements such as platinum group metals (PGMS) for sale on Earth.Appropriate targets are crucial to such missions, and relatively few are known. Elvis (2014) estimates only _ 2% _ 4% of NEOs are rich in PGMs and large enough to yield $1 billion in value, and only _ 3% of NEOs are rich in water. Further, target NEOs must also be energetically affordable, i.e. require a low Δv. NEOs that require low Δv to reach will allow greater payload mass to be delivered and/or greater mass to be retrieved. Hence, low Δv targets are strongly favored for asteroid missions, and many mission architectures call for discovery and characterization of additional prospective targets. In this work, we estimate how many low Δv NEOs exist and how many remain to be discovered in various size ranges. We couple the NEOSSat-1 model (Greenstreet et al 2012) to the NEO size distribution derived from the NEOWISE survey (Mainzer et al 2011) to compute an absolute NEO population model. We compare the Minor Planet Center catalog of known NEOs to this NEO population model. We compute the Δv to each NEO and model cell, and explore how NEO abundance varies with Δv and size class. We characterize where in (a,e,i) parameter space the low Δv objects are located. We demonstrate that the while the median Δv of the known NEOs is 7.3 km/s compared to a median Δv of 9.8 km/s predicted by our NEO model, suggesting that the population of undiscovered objects is biased towards higher Δv. The Amors show the lowest median Δv, making the most numerous class of NEO also the most energetically inexpensive to reach. Finally, we estimate how many NEOs remain to be detected as a function of size class and Δv. The survey of low Δv (Δv<10.3 km/s) is essentially complete for objects with diameter D>300 m. However, there are tens of thousands of objects with Δv<10.3 km/s to be discovered in the 50m<D<300m size class (H=20.3-24.1). By characterizing the Δv dependence of the undiscovered NEO population, we aim to help optimize astronomical survey strategies aimed at detecting these appealing low Δv targets by furnishing them with information regarding the most promising size class of objects to target in order to detect large numbers of asteroids. We also hope to furnish mission planners with information regarding the prospects for discoveries of additional prospective mission targets.

SSERVI-ESF14-013

Author: CHRISTOPHER RUSSELL

ORAL

Asteroid Population Characterization

The Mass and Speed of Interplanetary Field Enhancements

Multispacecraft observations of IFEs enable us to determine the speed and dimensions of these magnetic disturbances and determine the magnetic forces on the charged dust. The magnetic field configuration is that of a draped magnetic field pulling the charged dust cloud outward from the Sun. The speed of the disturbance is close to that of the solar wind so that the force balance is between the gravitational force of the Sun on the dust and the magnetic force of the IFE pulling and pushing outward. This enables us to weigh the charged dust cloud. In the dust cloud itself the magnetic field is sheared in the direction of the solar wind electric field as would be expected in a multicomponent charged-particle environment with greatly differing masses of the plasma. The masses obtained range as high as 10^12 kg. Such a disturbance is rare but is unambiguous as it lasts about 12 hours.

SSERVI-ESF14-014

Author: SERGEY VOROPAEV

POSTER

Asteroid Population Characterization

Comparative analysis of the space environment near-Earth asteroids using mineralogical data of micrograins from asteroid 25143 (Itokawa) and Chelyabinsk meteorite

Now, we have a lot of variety data concerning dust particles delivered by the Hayabusa spacecraft from the surface of near-Earth asteroid 25143 (Itokawa). It concerns chemical, mineral, isotope and a number of other analyses provided from japans' scientists, mainly. It turned out that Itokawa dust particles are identical to thermally metamorphosed LL chondrites and connect theirs with S type asteroids. From the other side, GEOKHI scientists have identified and characterized the major, minor and trace mineral phases in rock chips and dust of the Chelyabinsk meteorite, fall 15 February 2013, over Chelyabinsk, Russia. Raman spectra were shown for olivine, pyroxene, feldspar, magnetite, pyrrhotite (an Fe sulfide group) and, possible, carbonates. A number of analyses provided information on compositional variations of the above minerals and modal proportions of the rock which identify Chelyabinsk meteorite as LL5 S4 W0 ordinary chondrite. Thus, we have a minimally contaminated material, which we can use for the analysis of the possible relations between Itokawa and parent body of the Chelyabinsk meteorite.

SSERVI-ESF14-015

Author: JACK BURNS

ORAL

Astrophysics / Heliophysics (Including Space Weather)

Teleoperation of Rovers on Planetary Surfaces

The Global Exploration Roadmap identified telepresence and teleoperation of rovers on planetary surfaces as important parts of the strategy for exploration of bodies in the solar system. In this talk, I will present a Telerobotics Roadmap that begins with simulations using rovers on the ground remotely controlled by astronauts in the ISS progressing to teleoperation of a rover on the lunar farside operated by Orion astronauts and leading to human orbital missions around Mars. The first space-based surface telerobotics engineering tests using the K-10 rover at the NASA Ames Roverscape under the command of astronauts aboard the ISS were conducted in the summer of 2013. During three 3.5-hr ISS crew sessions, Kapton film strips which will form the backbone of a low frequency radio antenna array were successfully unrolled from the back of the K-10 rover. These ISS crew sessions achieved a number of "firsts" including the first real-time teleoperation of a planetary rover from the ISS, the first astronaut to interactively control a high fidelity planetary rover in an outdoor analog testbed, and the first realistic simulation of a human-robot "Waypoint" mission concept.The next step in the Telerobotics Roadmap is at the Earth-Moon L2 libration point in the early 2020's. This will provide an avenue to develop expertise needed for longer-duration missions in deep space and a platform to help discover answers to critical scientific questions concerning the origin of our solar system and the Universe's first galaxies. Potential mission objectives include performing real-time telerobotic exploration on the lunar surface, operating a libration point outpost to practice operations needed for deep-space exploration, and establishing an "interplanetary gateway", or assembly point for missions to more distant destinations. There are two primary science objectives for an "Orion L2 Farside Mission". The first would be to return to Earth multiple rock samples from the Moon's South Pole–Aitken (SPA) basin, one of the largest, deepest, and oldest impact basins in the solar system. A sample return from SPA was designated as a priority science objective in the National Research Council (NRC) Planetary Sciences Decadal Survey. The second objective would be to deploy a low radio frequency telescope, where it would be shielded from human-generated radio frequency interference from the Earth and free from ionospheric effects, allowing us to explore currently unobserved primitive epochs of the early Universe. Such observations were recently identified as one of the top science objectives in the NASA Astrophysics Roadmap.

SSERVI-ESF14-016

Author: DOUGLAS CURRIE

ORAL

Astrophysics / Heliophysics (Including Space Weather)

A LUNAR LASER RANGING RETROREFLECTOR ARRAY FOR THE 21ST CENTURY: STATUS AND SIMULATIONS OF APOLLO ARRAYS AND FUTURE SCIENCE

Lunar Laser Ranging (LLR) to the Apollo Retroreflector arrays has produced detailed information concerning the crust and interior of the moon (e.g., the discovery 15 years ago of the liquid core). It has also produced some of the best tests of General Relativity (i.e., the Strong Equivalence Principal, the Inertial Properties of Gravitational Energy, the Constancy of the Gravitational Constant G, etc.). This analysis continues to the present. However, the combination of the design of the Apollo arrays and the lunar librations now the limit the accuracy of the range measurements. Although the Apollo arrays are still operating and producing new science, Ground Stations (GSs) have improved their ranging accuracy by a factor of 200. As the moon liberates, the Apollo arrays of 100/300 Cube Corner Reflectors (CCRs) become tilted with respect the GS. This means that a photon reflected from the far corner of the tilted panel has a greater measured range than a photon that is reflected from the near corner. Thus the path to new lunar physics, gravitational tests and General Relativity tests is a new generation of lunar retroreflectors. The "next generation" retroreflector package being developed [1] and technical challenges of these measurements to the Apollo array will be discussed. This project, the "Lunar Laser Ranging Retroreflector for the 21st Century" or LLRRA-21 [1] is centered at the University of Maryland is being conducted within an international collaboration. Since the magnitude of the signal from the Apollo arrays has decreased, a detailed simulation [2] has been developed to identify the causes of the degradation in order to minimize their impact in the design of the LLRRA-21. The thermal/optical simulation is then compared to the observed returns from the Apollo arrays. It is especially helpful that the APOLLO station was able to obtain detailed observations during a lunar eclipse. During such an eclipse, the time constant of the changes of solar illumination is similar to the time constants of the CCRs and the array panel, thus providing critical new information for the simulation.Our nominal design is a system that will operate in both lunar day and night. This involves a sun shade and a pointing mechanism, the latter operating autonomously once shortly after launch. This system would weigh less than 3 kg. However, current rides have difficulty with this weight. As a result, we have investigated a non-shaded system that would mostly operate at lunar night. An analysis of this reduced schedule indicates that the loss of the science is minimal. Therefore for the first few rides, we expect to fly the system without sunshade nor pointing mechanism so the weight is less than a kilogram.

Author: ABHIRUP DATTA
POSTER

Astrophysics / Heliophysics (Including Space Weather)

Measuring Cosmic Dawn from the Farside of the Moon – DARE approach

The lunar far side is shielded from the Earth-based radio frequency interference (RFI) and is free of the limiting ionospheric effects on Earth. Thus, it is a promising site for precision radio astronomical observations even from an orbit above the Moon, as concluded by the recent NASA Astrophysics Roadmap. The Dark Ages Radio Explorer (DARE) is designed to measure the redshifted, sky-averaged 21-cm signal which is perhaps the most promising near-term probe of the end of the Dark Ages and Cosmic Dawn, when the first stars and galaxies began to heat and ionize the Universe. Measurements are challenging, however, because of the intense foregrounds at the relevant low radio frequencies (40-120 MHz corresponding to redshifts z=11–35) and the exquisite instrumental calibration this necessitates (1 ppm/ 106 dynamic range). DARE will orbit the Moon for a mission lifetime of 2 years and only take data above the lunar far side. Here, we outline the DARE mission, show the constraints it can place on the physics of the Cosmic Dawn, and demonstrate how the ionosphere puts a fundamental limit on the precision of similar, ground-based experiments. The DARE science instrument is composed of a three-element radiometer, including electrically-short, tapered, bi-conical dipole antennas, a receiver, and a digital spectrometer. Although the TRL (Technology Readiness Level) of the individual components of DARE instrument is high, the overall instrument TRL is low. One of the main aims of the entire DARE team is to advance the instrument TRL. Here, we present results from the latest engineering prototype which is deployed in Green Bank, WV, USA (a national radio-quiet zone).This research has been supported by the Lunar University Network for Astrophysics Research (LUNAR), headquartered at the University of Colorado Boulder and funded by the NASA Lunar Science Institute via Cooperative Agreement NNA09DB30A. Part of this research was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.

SSERVI-ESF14-018

Author: DAYTON JONES

ORAL

Astrophysics / Heliophysics (Including Space Weather)

Low Frequency Deployable Antennas for Space

The Jet Propulsion Laboratory (JPL) has been developing several deployable low frequency antenna concepts for use in space, particular in the lunar environment. These include antennas on spacecraft in lunar orbit and antennas for use on the lunar surface. In all cases the goal is to find low mass, low risk concepts for antennas that are physically large enough to be effective at frequencies below approximately 100 MHz. The primary scientific motivation for such antennas is observation of the highly redshifted spectral line of neutral hydrogen from the Dark Ages and Cosmic Dawn epochs, prior to the epoch of reionization. For some other scientific applications the relevant frequency range is below 10 MHz, corresponding to wavelength longer than 30 m. Recent results from JPL include prototype depolyable bi-conical dipole antenna for lunar orbiters, rover-deployed polyimide film antennas for the lunar surface, and inflation-driven film antennas for the lunar surface. Deployment and RF test results from all three concepts will be presented. Portions of this work have been supported by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration, and by the NASA Lunar Science Institute through the Lunar University Network for Astrophysics Research (LUNAR) collaboration.

Author: LEONID KSANFOMALITY

ORAL

Astrophysics / Heliophysics (Including Space Weather)

Possible life detected on the planet Venus' surface

Possible life detected on the planet Venus' surfaceL.V.Ksanfomality, Space Research Institute, Moscow, Russia leksanf@gmail.com The position of the hypothetical habitability zone in extrasolar planetary system was considered by many authors. Approximately 1/4 of exoplanets orbit their stars at very low orbits, which leads to high temperatures of their surface (if any), up to 800 K or more. Some of them should have the physical conditions close to those of Venus. Is there any possibility that the life forms can exist at quite different environment than "normal", Earth-like physical settings? Namely the planet Venus could be the natural laboratory for studies of this type, having the dense, hot (735 K) oxygenless CO2 - atmosphere and high, 9.2 MPa, pressure at the surface. It should be recalled that the only existing data of actual close in TV-observations of Venus' surface are the results of a series of missions of the Russian VENERA landers which took place the 1970s and 80s, working in the atmosphere and on the surface of Venus. No other results of this kind were obtained since. A re-exemination of images of venusian surface obtained from the VENERA landers has been undertaken using a modern processing technique, with a view to detect any possible signs of life under the specific conditions on Venus. This speculative identification rests on two characteristics of these features: (a) their somewhat suggestive morphology and (b) their temporal appearance and behavior (present, than absent on subsequent images of the same area; or changing appearances). The re-exemination has identified previously unreported features [1-4} that may correspond to hypothetical life forms on Venus' surface. Two of them, 'mushroom' (1) and 'amisada' similar to the Australian shingleback lizard in shape and size (2) are shown here. Analysis and comparison of the contents the sequence of panoramas of the venusian surface obtained in the course of the TV-experiments on the VENERA landers (1975-82), allowed the author to detect some interesting objects displayed on the panoramas. Following the change in their appearance on the sequence of images allowed a suggestion that such changes may be related to the possible habitability of the planet. Some of the objects found were described in few papers of L.Ksanfomality (2012). There are also found and listed in the report images of objects with special morphology resembling the shape of some terrestrial fauna. In the absence of new landing missions to Venus, the same study was carried out on the other remaining panoramas. There is a reason to believe that in the panoramas few class of unusual objects has been found, which will be shown in the report. References:[1] Ksanfomality L.V. 2013 Doklady Physics. 58 (5), 204[2] Ksanfomality L.V. 2013 Doklady Physics. 58 (11), 514[3] Ksanfomality L.V. 2013 International Journal of Astronomy and Astrophysics, 3, 57-79. [4] Ksanfomality L.V. 2014 International Journal of Astronomy and Astrophysics, 4, 29-38.

SSERVI-ESF14-020

Author: RICHARD MILLER

ORAL

Astrophysics / Heliophysics (Including Space Weather)

The Lunar Occultation Explorer

The Lunar Occultation Explorer (LOX) is a new _-ray astrophysics mission concept being developed to enhance our knowledge of the Cosmos in the nuclear regime. LOX will orbit the Moon and use the Lunar Occultation Technique to address science goals that include a deep all-sky survey and continuous monitoring of nuclear transients, exploration of galactic nucleosynthesis and the life cycle of matter in our Galaxy, compact objects such as black holes, and key questions related to solar flare dynamics. We will present an overview of the mission concept, its capabilities and developmental progress, as well as review the breadth of LOX science objectives.

SSERVI-ESF14-021

Author: ROBERT REID

POSTER

Astrophysics / Heliophysics (Including Space Weather)

Surface Operations Concepts: A Rover Demonstration of Sample Acquisition and Radio Antenna Deployment

A lander carrying a rover has an expanded mission potential. For sample return missions, a rover enables the acquisition of a range of spatially distributed samples. For radio antenna deployment, most likely applicable to missions using the lunar surface as a platform for heliophysics or astrophysics observations, a rover enables the deployment of an array of antennas.We illustrate the surface operations portion of a mission concept that combines these two potential capabilities. The Axel rover system is a family of platforms designed to provide versatile mobility for scientific access and human-oriented exploration of planetary surfaces in the solar system. We equipped one of JPL's Axel rovers with a percussive drill and a deployment mechanism for rolls of metallicized polyimide film. The drill had previously been demonstrated in acquiring powder samples from rocks, and the polyimide film had previously been demonstrated as a proof-of-concept radio antenna. The Axel rover was deployed in the JPL Mars Yard and operated remotely. Time delays of approximately 0.5 seconds were included in the operation of the rover— delays comparable to those likely to be experienced by astronauts in the cis-lunar environment tele-robotically operating a rover on the lunar surface and is only slightly shorter than traditional ground-based operation.In our surface operations demonstration, we illustrate the rover acquiring a powder sample, then deploying two radio antennas. We discuss "lessons learned" from this demonstration.Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

SSERVI-ESF14-022

Author: DAVID BLEWETT

POSTER

Dust / Regolith

Lunar crustal magnetic anomalies: Natural laboratories for space plasmas and geology

The Moon does not possess a global internally generated magnetic field. However the lunar crust contains areas of magnetized rock, tens to a few hundred kilometers in size. Many of the magnetic anomalies are located at the antipodes of major impact basins. The magnetic anomalies are also associated with highly unusual bright surficial markings known as lunar swirls. The origin of the magnetic anomalies and the bright swirl features is uncertain, though the observed correlation is very strong. There are several hypotheses for the origin of the swirls. These include atypical space weathering caused by stand-off of the solar wind, unusual dust accumulations or regolith texture related to electric fields associated with the magnetic anomaly, and scouring by cometary meteors, gas, or dust. The magnetic anomalies and swirls present a natural laboratory for investigation of several major areas in planetary science, including: (1) Planetary magnetism: What is the source of the magnetic anomalies? Are they related to an actively generated early lunar dynamo and/or to effects of large basin-forming impact events? Is the magnetized body an igneous intrusion, a deposit of magnetized basin ejecta, or a relatively thin surficial layer?(2) Lunar geology and space weathering: What is the nature and origin of the lunar swirls? The lunar magnetic anomalies potentially allow us to control for one of the key variables, solar wind exposure.(3) Plasma interactions with strong gradients in fields: What are the electric potentials, ion trajectories, and consequences for weathering of an airless silicate body with small-scale magnetic fields? What are the implications for backscattered particles and exosphere production by surface sputtering?

Author: DANIEL BRITT

Dust / Regolith

ORAL

Forward Modeling Space Weathering

Introduction: Space weathering is a generic term for the effects on atmosphereless solid bodies in the solar system from a range of processes associated with direct exposure to the space environment. The classic example of space weathering is the formation of the lunar spectral red slope associated with the production of nanophase Fe (npFe0) in the lunar regolith. But our understanding of the processes and products of space weathering has been limited by our access to pristine samples like the lunar soils and our necessarily limited view of surfaces provided by telescopic remote sensing. We have primarily focused on the most obvious aspects of weathering, such as the lunar red slope, but our limited data has also limited our view of this essentially physical and chemical phenomena. However, there is another way to explore space weathering that is not limited by observations or avail-able pristine samples. Space weathering can be viewed as the response of surface materials to inputs that drive the surface composition away from equilibrium, resulting in chemical reactions can be understood from the underlying thermodynamic driving forces. Using techniques and insight developed by materials science physics, especially related to surface science, we can assess the environment of the common asteroidal and planetary materials and forward model the expected results of the weathering reactions. This approach can help us understand the formation processes of known weathering products, predict the formation of other products, and identify already well-known materials as the products of weathering reactions. A General Theory of Space Weathering: Space weathering can be viewed as driven by a combination of the chemical environment of space (hard vacuum, low oxygen fugacity, solar wind implantation of hydrogen) along with thermal energy supplied by micrometeorite impacts. The forward modeling of space weathering as thermodynamically-driven decomposition of common rock-forming minerals suggests the production of a range of daughter products: (1) The silicate products typically lose oxygen, other volatile elements (i.e. sulfur and sodium), and metallic cations, producing minerals that are typically more disordered and less optically active than the original parent materials. (2) The decomposed metallic cations form in nano-sized blebs including npFe0, on the surfaces or in condensing rims of mineral grains. This creates the powerful optical component seen in the lunar red slope and also creates an environment for catalyzing further reactions.(3) The liberated volatile elements and gases (O, S, Na) may form an observable exosphere if sufficient quantities are available, and can either escape from the body or recombine with solar wind implanted hydrogen to form trace amounts of water and OH. Mineral decomposition can be thought of as the first stage of space weathering. It produces weathered surfaces somewhat depleted in volatile elements, creates a predictable set of minor or trace minerals, and leaves the surfaces with catalytic species, primarily npFe0. However, a second stage of further reactions and weathering depends upon the presence of “feedstock” components that can participate in catalyzed chemical reactions on exposed surfaces.

Author: RUSSELL COX

ORAL

Dust / Regolith

Peroxy as a Marker for Ancient Water, a Biohazard, and Dynamic Terminator Processes.

Water ice, condensed over time out of the vapor phase into permanently shadowed craters, is present on the moon. What about “ancient water”? It was there when the moon formed 4+ GYrs ago, at least in form of hydroxyl, such as O3Si-OH, in nominally anhydrous minerals. However, decades of studying lunar rocks from the Apollo era have led experts to believe that the moon is “dry” (where “dryness” is defined as absence or near-absence of O3Si-OH and the absence or near-absence of H). We challenge this view.Marker for Ancient WaterIn nominally anhydrous minerals most hydroxyl pairs disappear by way of a redox conversion in which the two hydroxyl oxygens transfer an electron to their respective protons: O3Si-OH HO-SiO3 _ O3Si-OO-SiO3 + H2. The two H form H2, while the donor oxygens, now in the valence O–, form a peroxy bond. As H2 is diffusively mobile, it can outgas. Left behind are peroxy as a “memory” of the former hydroxyl content. Therefore, if one sets out to find evidence for the “ancient water” on the moon, one must look – not for H or OH – but for peroxy. It is possible that peroxy will reveal a much greater reservoir of ancient water than has been previously detected.Source of Possible Biohazard for Human ExplorationWhen peroxy dissociate, they release highly mobile positive hole charge carriers, h•. Positive holes are defect electrons in the oxygen anion sublattice, chemically equivalent to O– in a matrix of O2–, which can also be written as •O radicals, known and feared for their highly oxidizing properties. In addition, due to their positive charge and mutual repulsion, positive holes accumulate at surfaces, edges and corners of finely comminuted regolith particles. Thus they could do extensive oxidative damage to the skin, mucous and lung tissues of future astronauts. Detectable Dynamic Terminator ProcessesIt is not yet known whether lunar rocks contain peroxy, we can design experiments to test it. When peroxy release positive holes, h•, these electronic charge carriers are highly mobile. They can flow out of the volume, where they were activated. They spread out at speeds around 100 m/sec over distances of meters to kilometers. Peroxy break-up is achieved by impact and by UV light. Hence, at the lunar morning terminator, h• charges will spill out of the illuminated surface over the surface still in shadow. Recombination of h• to peroxy leads to spectroscopically distinct IR emission, possibly also to a release of excited O atoms glowing at 630 nm, a process that might be important to understand in the context of emission of O atoms from the lunar surface. It may also be possible to detect a change in radar albedo between sunlit and shadowed conditions for the same surface.For landed missions, we propose to measure changes in electric ground potential and in electrical conductivity associated with the UV activation of the h• charge carriers at the morning terminator as a function or regolith depth.

SSERVI-ESF14-025

Author: RUSSELL COX

ORAL

Dust / Regolith

Lunar Lightning : The Need for Multi-Physics Modeling of the Impact Process

Up until now, the process of impacts on the Lunar surface has largely been considered as a kinematic process. We believe that it is time to consider the role of electromagnetic forces in the evolution of the impact as well as the novel chemical and physical processes that may evolve as the result of large currents in the ground and ejecta. We propose a three phase impact process that will require multi-physics modeling to understand and analyze.Phase 1) the kinematic evolution of bulk solids (this is well understood)Phase 2) large subsurface currents produced by the pressure wave of impact (seen in terrestrial Earthquakes)Phase 3) Development of plasma discharge in ejecta column (in analogy to hypervelocity impacts)Magnetic signatures are associated with some relatively young lunar impact craters [Halekas et al., 2003], though nothing is known about the orientation of the magnetic field vectors. Some craters show features, which suggest a powerful vertical electric discharge. We propose mechanisms by which (i) a halo of remnant magneti-zation would form through a powerful positive hole current pulse flowing outward upon impact, (ii) an large vertical electric potential would develop between the plasma plume and the impact crater. Both mechanisms are based on the discovery of a previously unrecognized type of defects, ubiquitous in all terrestrial igneous rocks and probably also in lunar rocks: pairs of defect electrons associated with the O2– sub-lattice, forming tightly coupled, electrically dormant peroxy such as O3Si-OO-SiO3. When activated by stress, the peroxy break up releasing positive hole charge carriers, highly mobile defect electrons h• associated with energy levels at the upper edge of the valence band. Terrestrial gabbro, when loaded within <1 msec, has been shown to produce positive hole outflow currents equivalent to ~109 A km-3. Such large currents may be crucial to understand the magnetic signature around lunar impact craters. At the same time, a strong electric field will build up between the negatively charged crater and the vertical plume, pointing to the possibility of a powerful lightning discharge through the electrically conductive plasma of the plume. The presence of positive hole charge carriers has far-reaching implications for the moon and other solid solar system bodies.The plasma interaction could range from dynamic chemical processes resulting in regolith and volatiles exposed to sunlight in the heated and charged ejecta plume to the possibility of very large plasma discharges of energies comparable to the impact itself. In any event, there is strong evidence that the effect of electromagnetic and plasma processes and chemistry my play a here to for unrecognized role in the evolution of impacts and them chemical evolution associated with gardening.Halekas, J. S., R. P. Lin, and D. L. Mitchell (2003), Magnetic fields of lunar multi-ring impact basins, Meteoritics &Planetary Science, 38(4), 565-578.

Author: BRADLEY DE GREGORIO
POSTER

Dust / Regolith

Aberration Corrected STEM Characterization of Glass Analogs for Regolith Grains on Airless Bodies

Space weathering of regolith particles on airless bodies leads to formation of nanophase Fe metal and amorphization of silicate minerals in the top ~100 nm of the grain surfaces (Keller and McKay, 1997, GCA 61, 2331-2341). Such changes can have a drastic effect on the optical properties of these bodies, in effect masking their true mineralogy and composition. Making a quantitative link between the atomic-to-nanoscale effects on the particles, and the macroscale properties is essential for maximizing the science return from exploration of airless bodies and returned samples. As part of the RIS4E collaboration, we are performing aberration-corrected scanning transmission electron microscopy (STEM) on analog samples to determine the atomic-scale structural and chemical effects of space weathering. Our samples consist of a series of basaltic glasses of varying composition and Fe oxidation state. The new Nion UltraSTEM 200 currently being installed at the Naval Research Library will permit quantitative energy dispersive X-ray spectroscopy (EDS) at scales down to single atom detection, and Fe oxidation state determination from measuring the relative intensities of the Fe2+ and Fe3+ L-edge peaks with electron energy loss spectroscopy (EELS) at an energy resolution of 0.3 eV. These nanoscale measurements will be coordinated with synchrotron X-ray absorption near-edge structure (XANES) spectroscopy of the same samples to extend the analyzed volume to the macroscale. In addition, principal component analysis (PCA) algorithms developed for analysis of the XANES spectra will be applied to the EELS data in order to identify characteristic spectral channels that are sensitive to changes in oxidation state (in addition to the typical Fe2+ and Fe3+ peaks).

Author: BRETT DENEVI
ORAL

Dust / Regolith

Global Variability in Regolith Properties on Vesta

The Dawn spacecraft spent nearly 14 months in orbit around 4 Vesta, mapping the asteroid with a framing camera (FC), a visible and infrared mapping spectrometer (VIR), and Gamma Ray and Neutron Detectors (GRaND). Despite differences in the depth of sensitivity of each instrument, most of our remote sensing information about Vesta comes from its regolith. Regolith is a mixture of local material comminuted by numerous small impacts, material excavated by distant impacts, plus a small contribution of exogenic material. Knowledge of the origin, depth, and mobility of Vesta's regolith is thus of consequence for a contextual understanding of results from each of Dawn's instruments.We investigate Vesta's regolith with several methods developed previously for the Moon and asteroids that can provide depth constraints, and taken together can provide a fuller picture of Vesta's regolith. These morphologic methods include assessing the presence or absence of coherent material within a crater's ejecta, examining crater walls, studying morphologic evidence for downslope movement and infilling of topographic lows with regolith, and documenting the preservation of small craters (formed mostly within the regolith) at different locations. The combined results from these methods are then compared to predictions of regolith depth based on the ejecta distribution expected for a model crater production function.From these studies, we find evidence for substantial regional variability in Vesta's regolith. A large equatorial region from ~100–240° E (Claudia system) contains a relative dearth of craters <10 km in diameter that have excavated blocky material, suggesting a regolith thickness >~1 km thick, or a more mobile regolith which can more rapidly bury blocks. This area also contains fewer craters that expose material resistant to erosion in their walls, and has a lower retention of small craters (<~300 m) that formed largely within the regolith. These features are consistent with a thicker-than-average regolith in the region, which is marked by a low albedo and relatively high hydrogen abundance. A thicker regolith in this region is consistent with the suggestion that the low albedo and high hydrogen are due to the accumulation of exogenic, carbonaceous debris in ancient, well-preserved regolith. This is in contrast to the Rheasilvia basin, with high albedo and low hydrogen, where we find a high concentration of blocky craters, exposures of material resistant to erosion in craters walls, and a larger population of small impact craters. These results are compared to numerical models of regolith production. Potential sites are identified where local bedrock may be exposed and the spectral properties of these sites are explored.

Author: GENEVIEVE DEVAUD

Dust / Regolith

ORAL

Asteroid Regolith Mechanical Properties: Laboratory Experiments with Cohesive Powders

We are conducting laboratory experiments to investigate the role of cohesion in governing regolith processes and geomorphological expression on small solar system bodies. Our goals are to develop an improved understanding of the geomorphological expression of granular media in the microgravity environments of regoliths on small asteroids and to quantify the range of expected mechanical properties of such regoliths.Many previous experimental results with cohesive powders have been obtained under ambient atmospheric conditions and we are reproducing some of those measurements for the sake of comparison. In the space environment the minimum distance between particles can be much closer than is possible on Earth, where atmospheric gases, water vapor, and relatively low temperatures allow for significant contamination of surfaces. In the extreme environment of space, surfaces are much 'cleaner' due to the lack of adsorbed molecules on the surfaces of materials, allowing for closer effective distances between surfaces so that the dipole-dipole interactions between molecules in the particle surfaces can come into play. Recognizing the significant role of surface contaminants and trapped air in cohesion and column failure, the bulk of our experiments are done under vacuum (mTorr) with previously vacuum baked powders in order to more closely simulate the environment and surface properties on an airless body. In the simulation side, we are using a Soft-Sphere Discrete Element Method code to replicate the results obtained with glass micro-spheres and as a means of validation. Simulations will allow us to control or remove some of the experimental constraints such as the confining walls, the uncertainty of the packing process and the strength of cohesive bonds. This will also allow us to better understand the failure mechanisms and their interplay with material properties. The environmental chamber for our experimental work resides at Ball Aerospace & Technologies Corporation (BATC) in Boulder, Colorado. Within the chamber our powder samples are manipulated within confined transparent walls to create piles and columns of powders that we can then tilt or otherwise interact with to induce sloped failures, faults and fractures, and other morphological features that provide data on the self-cohesive forces at play. The powders used in our experiments include JSC-1A, 3-micron glass microbeads, and, for familiar context, ordinary unbleached white flour.In addition to examining and quantifying the morphology of faults and fractures in our powder columns and piles and the angles at which slope failures occur, we have to date noted with interest that the talus slopes resulting from the collapse of the columns and piles often contain a number of distinct 'boulders' formed from self-cohered 'clods' of the powder material. The superficial resemblance of these 'boulders' to the coarse fraction of the regolith in regions of the surfaces of Eros and Itokawa suggests that some care be applied in interpreting all such large fragments on these objects as necessarily composed of competent hard rock.

Author: GENEVIEVE DEVAUD

ORAL

Dust / Regolith

Engineering surfaces to shed particles: A solution to a dusty problem?

Tenacious adhesion of dust to surfaces in the vacuum environment of space is viewed as one of the biggest obstacles to exploration and scientific discovery on the Moon, Mars and asteroids. Mitigating particle adhesion is also costly and difficult during semiconductor or optics processing on earth. Particle adhesion on surfaces is a complex, poorly understood phenomenon in spite of many years of study. On the surface of an airless body, adhesion is mediated predominantly through van der Waals and Coulombic interactions due to charging by the solar wind, and highly reactive, clean surfaces. Over the last ten years at Ball Aerospace & Technologies Corp (BATC), we have demonstrated the effectiveness of an ion beam process that dramatically reduces the adhesion of lunar simulant dust to quartz, glass, Kapton, Teflon and silicon surfaces in dry, ambient, and vacuum environments. We call this the STAR process, for Surface Treatment for Adhesion Reduction. STAR silver-coated Teflon coupons performed well in a head-to-head comparison of three competing types of dust mitigating surfaces in a space-simulated environment at NASA Glenn Research Center. Cooled substrate materials were bombarded with ions generated by a commercially available Kaufman ion source approximately 2 feet away. After ion beam treatment we deposited different types of dust onto the surface, including JSC-1AF lunar simulant, JSC MARS-1A Martian simulant, silica spheres, high Ti basalt, aluminum oxide and calcium oxide powders. We deposited dust by sieving a monolayer onto the surface, or by dumping dust by the spoonful to simulate different types of deposition. Effectiveness of dust removal was monitored optically and reported as percent area coverage following removal by centrifugal detachment or by tapping and gently blowing with nitrogen gas, respectively. As an example, virgin silicon surfaces retain 22% PAC of dust after removal, as compared with 1% PAC dust coverage after removal from STAR surfaces. This performance has been retained over several years of exposure to ambient environments and repeated dusting. Atomic force microscopy is the gold standard for evaluating surface structure, and we found that surface roughening on an Ångstrom-level scale was found to correlate well with reduced adhesion. Contact angle hysteresis was also found to be an effective process tool for evaluating effectiveness of dust adhesion reduction. The large difference in advancing and receding contact angles reflects topological and/or chemical heterogeneity. We found that contact charge transfer between the particles and STAR surfaces was not consistently different from that of the virgin surfaces. The extent of contact charge transfer is notoriously variable, even between "identical" materials. This method of reducing adhesion of particles to surfaces is particularly attractive for optical or thermal control materials as the intrinsic properties of the material are maintained. This method could also be nicely paired with the highly effective electrodynamic screen to reduce voltage requirements.

Author: CHARLES EL MIR

ORAL

Dust / Regolith

ORIGIN AND EVOLUTION OF REGOLITH ON AIRLESS BODIES: THE ROLE OF THERMAL FATIGUE

The surface of planetary bodies is of interest as it is the part observed with remote sensing instruments, and the part that will be sampled by sample return missions. Images obtained through space missions [1,2], infrared and radar observations [3,4] and returned samples [5] re-veal these surfaces are covered by a layer of loose, unconsolidated, debris referred to as 'rego-lith'. Understanding the formation and evolution of regolith as well as the variation of these pro-cesses will provide insight into the origin, age, and properties of these bodies.Regolith generation and evolution is typically attributed to re-accumulation of ejecta as well as continuous micrometeoroid impact leading to the breakdown of boulders [6, 1]. While this model can explain lunar regolith, it may not be applicable to kilometer-sized asteroids. Im-pact velocities on main-belt asteroids (~5km/s) are much lower than on the Moon (~15 km/s) and are therefore less efficient in shattering asteroidal rocks. Laboratory experiments [7] and impact models [8] show that crater ejecta velocities tend to exceed the escape velocity of asteroids. An alternative mechanism of regolith formation is fracturing due to thermal fatigue by diurnal cy-cling. Such a phenomenon was noted as a mechanism for fracturing of rocks in cold and hot ter-restrial environments [9]. Dombard et al. [10] attributed the formation of ponds on Eros to ther-mally disaggregated boulders, and Delbo et al. [11] demonstrated the importance of thermal fragmentation for regolith production and surface rejuvenation on asteroids. Thermal fragmenta-tion also has the effect of weakening surface rocks, thus increasing the efficiency of rock commi-nution by micrometeoritic impact.This study aims to characterize the thermal fragmentation by examining its viability in producing regolith. Thermal fragmentation is studied as a function of temperature range, rate, petrology, grain size, and size-frequency distribution of the resulting particles. It is noted that areas of lunar permanent shadow [12] provide the potential to test the relative importance of thermal fragmentation models. These areas do not experience a diurnal thermal cycle; thus, fragmentation would be exclusively due to micrometeorite bombardment. Surface properties and fragment distributions can be measured and compared with areas that experience thermal cycling. In this context, fatigue experiments will be conducted to provide the necessary input parameters for the thermal fragmentation mechanism in a regolith formation and evolution model. Digital Image Correlation (DIC) will be used to obtain full-field strain maps as a consequence of fatigue crack growth, and these strain maps will be used to help determine the driving force on the crack tip. The recorded images by DIC technique will be also utilized to measure fatigue crack growth rate.

Author: NIMA GHARIB

ORAL

Dust / Regolith

Dust cleaning, transportation and sampling in lunar environment using traveling electric field

Unlike Earth, moon does not have a magnetic field to protect it from high energy particles emitting from the Sun. Once they reach the surface of the moon, they penetrate into the dust particles and remove their electrons leaving them positively charge on the day side. On the dark side electron plasma makes the surface negatively charged in the order of thousands of volts. Since the materials composing regolith have low conductivity and there is no atmosphere on the moon, the dust particles tend to keep their electrical charge. The charge particles repeal themselves and hover above the surface. From Apollo documents all the lunar surface activities inversely affected by highly abrasive and electrically charged dust particles which cover everything they come into contact with. In this study, the possibility of using electrostatic and dielectriphoretic forces in dust removal from rover equipments is addressed. Electrodes placed parallel to one another shaping planar, cylindrical, and spherical configurations connected to a voltage source generating a traveling electric field which applies force to the charged particles and move them along or against the field. Applied frequency, voltage amplitude and shape, inclination angle, and particles shapes are the parameters their influence were examined on cleaning efficiency of the device. The results show this technique can remove 75 to 95 percent of the accumulated dust on surfaces.Furthermore, applications of traveling electric field in transporting dust particles between two points, e.g. moon surface to an on-board lab, and separating and sorting particles based on their electrical charge s and mass for geotechnical sampling and examinations were investigated.

Author: TIMOTHY GLOTCH

ORAL

Dust / Regolith

Spectral and Thermophysical Properties of Phobos from the Mars Global Surveyor Thermal Emission Spectromete

The spectral properties of Phobos have been previously investigated at both visible/near-infrared and mid-infrared wavelengths. These works have shown that Phobos spectra include a broad 0.65 micron feature that may be attributable to Fe-bearing phyllosilicates or Rayleigh scattering by nanophase metallic Fe particles. VNIR spectra of Phobos also include a 2.8 micron metal-OH feature that may be diagnostic of desiccated phyllosilicates or solar wind-induced hydroxylation of the Phobos regolith surface. At mid-IR wavelengths, Phobos displays a variety of spectral classes, which are consistent with tectosilicates, such as feldspars and mixtures of phyllosilicate minerals. In this work, we re-evaluate MIR spectra of Phobos acquired by the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) experiment. We gathered TES spectra from four early mission TES aerobraking orbits (orbits 476, 501, 526, and 551) and culled the data to include only the highest temperature daytime observations of the Phobos surface. For the surface of Phobos, subpixel temperature mixing is clearly an issue. Therefore, we modeled the radiance of the surface as a linear combination of blackbodies of many different temperatures. The resulting emissivity spectra occasionally have emissivity values greater than unity, but are not affected by strong slopes due to surface anisothermality.Surface emissivity spectra of Phobos display a variety of spectral shapes while having some features in common. Most spectra display a strong drop in emissivity shortward of the Christiansen Feature (CF), typical of finely particulate silicates. Average spectra all have modeled CFs in the 8.34 to 8.4 micron range, indicating an olivine/pyroxene-dominated surface if the surface is optically immature (devoid of space weathering). It has been shown for the Moon, however, that optically mature surfaces have CF positions that tend to be shifted by ~0.2 microns to longer wavelengths compared to optically immature surfaces of the same composition. Assuming the average surface of Phobos is optically mature, corrected CF positions of 8.14 to 8.2 microns indicate a more feldspar-rich surface. This is consistent with VNIR observations, which lack strong 1 and 2 micron Fe^{2+} absorption features and longer wavelength MIR transparency features that are consistent with finely particulate tectosilicates such as feldspar.   Nearly all spectra display emissivity maxima at ~6 microns, consistent with varying levels of surface hydration. This hydration feature may be due to water bound in minerals or transient water formed through interaction of the solar wind with the Phobos surface. The relatively strong 6 micron features found in the TES data are somewhat surprising due to the lack of a strong 3 micron water band in VNIR observations of Phobos. Finally, some spectra display emissivity maxima at ~6.7 microns, which has been shown to be consistent with small amounts of carbonates intimately mixed with silicates. This observation may support the hypothesis that Phobos is a captured D-type asteroid, similar in composition to the Tagish Lake meteorite, which is carbonate-bearing.

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Author: EBERHARD GRUEN

ORAL

Dust / Regolith

Dynamical and Collisional Timescales of Meteoroids Released From Jupiter Family Comets

Large dust particles (meteoroids) released from comets are initially spread along the orbit of their parent body. This spreading is caused by variations in the initial release conditions of the particles, such that they have slightly different orbital periods to their parents. Close planetary encounters (mostly by Jupiter) scatter meteoroids through interplanetary space. Simultaneously collisions with interplanetary meteoroids shatter cometary meteoroids and generate large amounts of smaller fragment particles. An understanding of the importance of these three mechanisms is required to determine how a meteoroid stream disperses into the interplanetary background. To this end, we compare the timescales for spreading, scattering, and shattering of meteoroids released from Jupiter family comet 67P/CG. Jupiter family comets currently provide a major source of meteoroids to the interplanetary complex. Their orbits are characterized by frequent encounters with Jupiter. Comet 67P/CG is a typical member of this class of comets. The initial spreading of meteoroids is calculated by studying the initial velocities of the particles. The effect of Jupiter scattering is simulated on a string of particles along the comet's orbit. The timescale of planetary scattering is compared to the timescale imposed by the Poynting-Robertson effect. The effects of shattering are determined for meteoroids of masses 10^-6, 10^-3, and 1 g. By applying the ESA IMEM meteoroid model (Dikarev et al., 2005, Advances in Space Research 35:1282) to meteoroid stream particles at various positions along their orbit we calculate their collisional lifetimes, and compare them with timescales for spreading, scattering, and shattering. Our results have implications for the total lifetime of meteoroid stream particles that originate from Jupiter family comets.

Author: EBERHARD GRUEN

ORAL

Dust / Regolith

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Author: MIHALY HORANYI
ORAL

Dust / Regolith

LUNAR IMPACT EJECTA CLOUDS OBSERVED BY LDEX

The Lunar Dust Experiment (LDEX) onboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission successfully mapped the spatial and temporal variability of the dust size and density distributions in the lunar environment. LDEX reliably detected and measured the mass of submicron and micron sized dust grains, while in lunar orbit from 10/6/2013 - 4/17/2014. LDEX also measured the current from low-energy ions and collective charges from dust impacts that are below the detection threshold for individual dust detection, enabling the search for the putative population of grains with radii ~ 0.1 micron lofted over the terminator regions by plasma effects. LDEX has identified and characterized the dust ejecta cloud that is maintained by the sporadic micrometeoroid bombardment of the lunar surface. The density of the dust ejecta cloud increases with decreasing altitude, and shows significant enhancements during meteor showers. LDEX found no evidence of the plasma-lofted particles, and put strict new upper limits on the density of the high-altitude small grains. _The discovery and detailed understanding of the lunar ejecta cloud opens new pathways to learn about the dust populations comprising the sporadic background and the meteor showers, as well as the response of the lunar regolith as function of the mass and speed of the bombarding particles. The collected data will be further used to improve dust hazard models for the near-Earth environment. Ejecta clouds, similar to that observed around the Moon are likely to be present at other objects that are possible targets for future human exploration: asteroids, and the Martian Moons Phobos and Deimos. An LDEX-type instrument on precursor missions will greatly contribute to the safety of the crew and the mission to these targets.

Author: GEN ITO

POSTER

Dust / Regolith

Calculating the Scattering Properties of Fine-grained Particulates of Planetary Surfaces

Determining the compositions of fine particulates, such as the regoliths of the Moon and near Earth asteroids, has been a problematic task in infrared remote sensing. Difficulty in modeling the scattering properties arises due to the multiple scattering, absorption, and transmission of light that occurs when regolith particles have diameters equal to or smaller than the wavelength of light being used by an instrument. Radiative transfer models have been used to calculate the emissivity of closely-packed, fine particles with some success, but these models cannot fully describe the behavior of emissivity spectra. Although the radiative transfer models have been adjusted to account for closely-packed particles, the physics of radiative transfer only holds for truly well-separated particles. The closely packed nature of planetary regolith particulates may be the fundamental cause of inadequate modeling by various radiative transfer models, and therefore, this study takes a different approach where the scattering properties from a single cluster are calculated in which the cluster is composed of many particles. Scattering by each individual particle is calculated by exactly solving Maxwell's equations at every light and particle interface using the publicly available Multiple Sphere T Matrix code. Then, the cluster-averaged scattering properties of a single volume are input into Hapke's equation for hemispherical emissivity. This approach allows us to correctly calculate the near-field scattering properties of regolith particles to generate a cluster-averaged single scattering albedo. Previous works have shown that this method can generate more accurate emissivity spectra. Following their example, we generated a cluster containing 150 closely-packed spheres of olivine composition with 10 _m diameters. Another cluster composed of spheres with diameter of 100 _m was also generated, but using 10 spheres due to computing constraints. Within a wavenumber range of 100 – 2000 cm-1, correct optical constants of olivine and corresponding scale factors were assigned to the clusters. Using these inputs, we executed the MSTM code on NASA's Pleiades supercomputer located at Ames Research Center. Our work compares the quality of the exact calculation method to those from various scattering models, including Mie theory, the Hapke emissivity model, and a hybrid Mie/Hapke model. Furthermore, we will explore the effects of cluster size, particle size distribution, compositional heterogeneity, and particle shape and compare our model results with laboratory measurements to validate the accuracy of this model.

Author: THOMAS KEHOE
POSTER

Dust / Regolith

Understanding Asteroid Regolith Properties from the Post-Disruption Evolution of Dust Bands

We have performed dynamical modeling of the structure of a faint dust band observed in carefully co-added IRAS data at an ecliptic latitude of 17º that convincingly demonstrates that it is the result of an extremely recent (significantly less than 1 Ma ago) disruption of an asteroid and is still in the process of forming. Our detailed modeling of the 17º partial dust band has led to a new understanding of the information that is preserved in these young structures about the original source body and the disruption process. In particular, we show that young dust bands retain information about both the size distribution and cross-sectional area of dust released in the original disruption, before it is lost due to orbital and collisional decay.As a result of this modeling, we can confidently link the 17º partial dust band with the Emilkowalski cluster based not only on its ecliptic inclination but also on its node, semimajor axis, and its age, which we show to be consistent with the value of 220 ±30 ka determined for the age of the Emilkowalski cluster by Nesvorny´ et al. (2006). We also found that the inclination dispersion of the dust particles is more than would be expected for a low ejection velocity and that ejection velocities of a few times the escape velocity of the Emilkowalski cluster source body provide a better fit of the models to the observations.We determine that the cross-sectional area of dust currently associated with the band is on the order of 10^6 km2 and the cross-sectional area of dust initially released by the disruption of the Emilkowalski cluster source body is on the order of 10^7 km2. This would correspond to a regolith layer ~3 m deep on the ~10 km diameter source body's surface. We discuss the implications that such a significant release of material has for the temporal evolution of the structure, composition, and magnitude of the zodiacal cloud.For the young 17º partial dust band, we find a lower bound on the cumulative size distribution inverse power-law index of 2.1, for dust particles with diameters ranging from a few μm up to a few cm, indicating that the cross-sectional area of ejected material is dominated by the smallest of these particles. Interestingly, this is a much steeper size distribution than the 1.2 cumulative inverse power-law index found for the older central and 10º bands (Grogan et al., 2001; Espy et al., 2010). This implies that small particles are being removed, as the dust band ages, at a faster rate (due to orbital decay caused by radiation forces) than they are being replenished (due to inter-particle collisions), and that results obtained from modeling older, fully-formed, dust bands will underestimate the contribution of small particles to the original disruption ejecta.

SSERVI-ESF14-038

Author: SASCHA KEMPF

ORAL

Dust / Regolith

PROPERTIES OF THE LUNAR DUST EXOSPHERE AS SEEN BY LDEX

Impacts of fast interplanetary meteoroids with the Lu-nar surfaces produce ejecta particles which populate tenuous, approximately isotropic clouds around the moons. This process is very efficient: a typical inter-planetary 10-8 kg micrometeoroid impacting the Earth' Moon produces a large number of dust particles, whose total mass is about 650 times that of the impactor. The ejecta particles move on ballistic trajectories, most of which have lower initial speeds than the moon's escape velocity and re-collide with the surface, while particles ejected fast enough to escape from the moon's gravity may form tenuous dust rings such as Jupiter's gossamer rings. The Lunar Dust EXperiment (LDEX) on the Lunar Atmosphere and Dust Environment Explorer (LADEE) was the first instrument flown in the vicinity of the Moon, which is sufficiently sensitive to observe the lunar dust exosphere. This talk will report about first insights into the properties of the Lunar dust exo-sphere. The observed scaling of the impact rate with the distance to the Lunar surface is in rough agreement with mean field models of planetary dust exospheres.

Author: JAMIE MOLARO

Dust / Regolith

POSTER

Thermoelastic grain-scale stresses on airless bodies and implications for rock breakdown

Most studies on the thermomechanical breakdown of rocks focus on arid, terrestrial environments where other weathering processes are slow. Propagation of microfractures in rocks occurs due to expansion and contraction caused by changes in temperature, and by mismatches in thermal expansion behavior of adjacent mineral grains. Airless bodies may provide an environment uniquely suited to this process, as many experience large diurnal temperature ranges, rapid changes in temperature during sunrise and sunset, and/or high thermal cycling rates due to rapid rotation. Thermal breakdown of materials has been suggested as an active process on various airless bodies, including the Moon, Mercury, Vesta, Eros, and Phaethon, however the extent of the damage produced as a result is unknown. Historically, the effectiveness of this process has been assessed by rates of surface temperature change, with a threshold of 2K/min required for permanent damage. Here we link surface temperatures and spatiotemporal temperature gradients to actual stresses near rock surfaces in order to better judge the efficacy of thermal weathering on different planetary bodies. In this study, we employ finite element simulations of the thermoelastic behavior of microstructures with varying grain sizes and thermophysical properties. We imposed the solar and conductive fluxes calculated by a 1D thermal model at the surface and at 5 mm depth on a microstructure of mineral grains over one solar day. The microstructure is a randomized grid of hexagonal grains (0.3mm in diameter), 25% of which are assigned properties of plagioclase, and 75% pyroxene. The heat and displacement equations are solved over a solar day on a Lunar equatorial surface. Preliminary results indicate that these surfaces experience a diurnal maximum effective stress (or von Mises stress) of 150 MPa while under tension. This peak stress occurs pre-dawn when the microstructure is coldest, indicating that stresses are predominantly controlled by temperature rather than temperature gradients. Typical tensile strengths of rocks are on the order of 100 MPa, suggesting that thermomechanical fracturing may be possible on the Moon, but not necessarily on other bodies. Similar model runs on Vesta and Phobos produce peak tensile stresses of only 5 and 13 MPa, respectively. Phobos is somewhat unique and experiences a secondary spike in tensile stress of 6 MPa due to a midday eclipse that occurs near martian equinoxes. Examination of the microstructure during the peak tensile state reveals that stresses are concentrated along surface-parallel grain boundaries, suggesting that after temperature, it is the heterogeneity of a rock that dominates its thermoelastic behavior. Examination of the microstructure over time reveals an anti-correlation between high stresses and large spatiotemporal temperature gradients, indicating that rates of surface temperature change are not an effective proxy for stress.We will present model results of thermoelastic stresses induced within microstructures with varying grain properties and distributions for a variety of airless bodies. This work represents the first step in quantifying the contribution of thermal stress weathering to regolith production rates on these bodies.

Author: TOBIN MUNSAT
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Dust / Regolith

Ice Target and Gas Target Experiments in the IMPACT Dust Accelerator

The dust accelerator facility at the SSERVI Institute for Modeling Plasma, Atmospheres, and Cosmic Dust (IMPACT) is presently implementing two major target upgrades: a cryogenic ice target and a high-pressure gas target. The ice target consists of a LN2 cryogenic system connected to both a water-ice deposition system as well as a movable freezer/holder for a pre-mixed liquid cartridge. Planned experiments include the bombardment of a variety of frozen targets and simulated ice/regolith mixtures, and the assessment of all impact products (solid ejecta, gas, plasma) as well as spectroscopy of both the impact-produced light flashes and the reflected spectra (UV, visible, IR). Such measurements are highly relevant to both physical and chemical surface modification of airless bodies due to micrometeoroid impacts. The gas target consists of a differentially pumped chamber kept at moderate background pressures, such that high-velocity (~10 km/s) micrometeoroids are completely ablated within 10's of cm (i.e. within the measurement chamber). The chamber is configured with segmented electrodes to perform a spatially-resolved measurement of charge production during ablation, and localized light-collection optics enable an assessment of the light production (luminous efficiency). Such studies are critical to the understanding of past and future ground-based measurements of meteor ablation in Earth's atmosphere, which in turn can potentially provide the best estimates of the interplanetary dust particle flux

Author: CARLE PIETERS
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Dust / Regolith

The Special Environment of Lunar Swirls

Lunar swirls are some of the most beautiful and enigmatic features on the Moon. They are characterized by their unusual albedo markings, which are wispy or sinuous in form. Swirls are often associated with the invisible presence of notable magnetic anomalies. They are found without any topographic expression of their own and occur across mare or highland terrain. We have recently re-examined the spectroscopic properties of swirls using data from the Moon Mineralogy Mapper in order to determine whether there are compositional distinctions associated with their bright and dark markings. The data are consistent with the features being locally derived (rather than addition of a significant foreign component), but their albedo variations do not follow any common alteration or mixing pattern for lunar materials. Specifically, the spectral properties of swirls are not consistent with normal 'space weathering' of exposed lunar materials that results from the accumulation of nanophase metallic iron on soil grains when exposed to the harsh environment on the lunar surface. Instead, the observed characteristics of swirls argue for a difference in micro-scale texture of swirl regolith structure compared to that of nearby local soils. Some rearrangement of the fine components is also likely at swirls. Important issues to explore in the lunar environment are the effects that a relatively strong local magnetic field may have on small electrostatic forces that control interaction between soil grains. The mobility of the finest fraction is another key question as well as the strong diurnal cycling involving solar radiation and solar wind energetic particles. If we could understand the direct cause and effect between the magnetic anomalies and the character and patterns in these enigmatic swirls, we would go a long way toward constraining the origin of the magnetic signatures themselves – which in turn would ultimately constrain the early history of the Moon.

Author: ANTHONY SHU

POSTER

Dust / Regolith

Cratering Studies in Thin Plastic Films

Thin plastic films, such as Polyvinylidene Fluoride (PVDF), have been used as protective coatings or dust detectors on a number of missions including the Dust Counter and Mass Analyzer (DUCMA) instrument on Vega 1 and 2, the High Rate Detector (HRD) on the Cassini Mission, and the Student Dust Counter (SDC) on New Horizons. These types of detectors can be used on the lunar surface or in lunar orbit to detect dust grain size distributions and velocities. Due to their low power requirements and light weight, large surface area detectors can be built for observing low dust fluxes. The SDC dust detector is made up of a permanently polarized layer of PVDF coated on both sides with a thin layer ($\approx$ 1000 Å) of aluminum nickel. The operation principle is that a micrometeorite impact removes a portion of the metal surface layer exposing the permanently polarized PVDF underneath. This causes a local potential near the crater changing the surface charge of the metal layer. The dimensions of the crater determine the strength of the potential and thus the signal generated by the PVDF. The theoretical basis for signal interpretation uses a crater diameter scaling law which was not intended for use with PVDF. In this work, a crater size scaling law has been experimentally determined, and further simulation work is being done to enhance our understanding of the charge generation from the detector. An electrostatic Poisson relaxation code is used in conjunction with the experimentally determined scaling law to determine the veracity of current theories on charge generation in PVDF detectors. Experimental results and simulation results and conclusions will be presented.

Author: CHAE KYUNG SIM

POSTER

Dust / Regolith

Multi-Band Polarimetric Observations of the Lunar Surface

We carried out multi-band (U, B, V, R, and I passbands) polarimetric observations of the whole near side of the moon from the Lick observatory using a 15-cm reflecting telescope. Polarization of the light scattered by the lunar surface contains information on the mean particle size of the lunar regolith, which gradually decreases by continued micro-meteoroid impact over a long period and thus is an age indicator of the surface. We present a map of the mean particle size for the whole near side of the moon. We also compare our observations with the computer simulations and laboratory experiments that we recently began to conduct.

Author: JONAS SIMOLKA

ORAL

Dust / Regolith

Development of a Gas Impact Chamber for Laboratory Studies of Meteoric Ablation

A gaseous target for hypervelocity dust particles is developed for the laboratory study of micrometeoroid ablation in the Earth's and planetary atmospheres. The dust accelerator facility at LASP, University of Colorado at Boulder is used to accelerate micron and submicron sized dust particles to relevant velocities, > 10 km/s. The gas impact chamber is 40 cm long and is pressurized to 0.02 – 0.5 Torr using dry nitrogen or other gases. At the low end of the pressure range the particles will undergo deceleration due to air drag, and at high end they will completely ablate. There are three main diagnostic methods: (1) There is an impact ionization detector at the end of the chamber that measures the mass of the remaining particle. The timing of the impact yields the impact velocity and the deceleration from air drag. (2) The electrons and ions produced during ablation will be collected on a set of biased electrodes. There are two sets of 16 electrodes arranged along the top and bottom of the particle's path in the ablation chamber. The electrodes are biased to separate the positive and negative charges of the ablation plasma and each electrode is connected to a separate charge sensitive amplifier. These electrodes are the main monitors of the ablation process by detecting the produced charge along the particle's path, determine the ionization probabilities of the ablated material, and observe differential ablation the first time. (3) Photomultiplier tubes are mounted to the chamber to detect the light emitted by the hot particle and its final impact, and monitor the emission from the impact ionization process. The pressure in the chamber is monitored using an absolute vacuum gauge. There is a two stage differential pumping system that connects the ablation chamber to the high-vacuum beam line of the dust accelerator. The talk will present the science motivation and design of this new SSERVI/IMPACT facility, the calibration of the diagnostics, and the first test measurements.

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Dust / Regolith

LADEE/LDEX Observations of Meteor Streams at the Moon

The lunar surface in continually bombarded by meteoroids from a variety of sources. Upon impacting the lunar surface, each meteoroid can produce ejecta plumes with hundreds of times more mass than the incoming meteoroid, lofted 10's to 100's of km above the lunar surface. The Lunar Dust Experiment (LDEX) onboard the LADEE mission measures the response of the lunar surface to meteoroid bombardment. For their brief duration, meteor streams can deliver higher impactor fluxes than the continual bombardment by the sporadic background of interplanetary dust particles. During peak shower times, the dust production from the surface can dramatically increase. Of all known meteor showers during the LADEE mission, the Geminids produced the strongest lunar response, for which LDEX observed significantly enhanced fluxes with a strong clustering near the point of maximal Geminids flux on the lunar surface. This talk will present a comparison of the meteor shower activity with the intermittently observed, unusually high impact rates recorded by LDEX. We also report on the differences in the physical properties of the ejecta particles generated during meteor streams and from the sporadic background. Characterizing the response of the lunar environment to known meteor streams will help identify unknown meteor streams in future missions to airless solar system bodies. This will aid in improving hazard estimates were an LDEX-type instrument to fly to future human exploration targets.

Author: LAWRENCE TAYLOR

ORAL

Dust / Regolith

UNDERSTANDING LUNAR SOILS: AN APOLLO PERSPECTIVE

Nine scoops of lunar soil were added to one of the rock boxes during Apollo 11, in order to keep the rocks from "rattling around". This 10 kg of soil was sieved, and the <1 mm fraction was designated as soil 10084, one of the most studied of all lunar samples. Yes, this soil was used in place of the unavailable 'popcorn' for packaging, not as a specific dedicated sampling of soil; and much of the Apollo soils were simply the packing materials. But why is "corporate memory" valuable?In spite of the first Apollo soils coming back in July, 1969, it took almost three (3), yes, 3 years for the nature of the strange magnetic susceptibility of the soil to be figured out – no magnetite; no Fe3+ - our "Terrestrial Hats" led us astray. Native Fe? Yes, the soils had been formed by meteorite and micro-meteorite bombardment = metallic Fe. But, the actual lunar basalts had native Fe as a mineral formed during the normal igneous crystallization. However, the Ferromagnetic Resonance (FMR) analyses detected a strange, at that time unique, Single Domain Fe signature for metallic Fe between 33 and 300 Å (3-33 nm) (Morris, 1974). It was this SD-Fe [IS] that became the symbol for "Soil Maturity", when combined with the total iron in the soil expressed as FeO - "IS/FeO". And the origin of this SD-Fe was speculated as solar-wind reduction of impact-produced melt that effectively 'glued' agglutinates together (Housley et al., 1973). It took an additional 2 decades to solve that actual true formation of this SD-Fe as selective vaporization and subsequent deposition of super-heated soil melt – "reduction" by thermal dissociation (Keller & McKay, 1993). Somewhere over time, in the '90s, the term "nano" became the sexy word of choice, whereby the SD-Fe became "Nanophase Fe" – NP-Fe, but with the loss of peoples' memory that this np-Fe was to be the same as SD-Fe. Was this the remote-sensing community? And then along came the "Synthesizers", who were making lunar soil simulants with NP-Fe in them. But like the SD-Fe in lunar soil that gives the FMR IS signal similar to lunar – the IS/FeO? No way! Even after the $M that have been spent in such endeavors. Is corporate memory valuable? You betchu!

SSERVI-ESF14-047

Author: XU WANG

ORAL

Dust / Regolith

Interactions of a plasma flow with a magnetic dipole field: Implications for large positive lunar surface potentials

Recent in-situ observations, as well as computer simulations, indicate that the lunar surface may be charged to potentials from +150 up to +300 V in magnetic anomaly regions. This is much higher than the generally expected value of ~ +10 V on the dayside surface due to the photoemission. We present new laboratory experiments studying the interaction of flowing plasmas with magnetic dipole fields to address these unexpected observations and modeling results. A plasma flow with an ion energy varying from 10 to 50 eV is created to interact with a magnetic dipole field above an insulating surface. We investigated the case of a moderate strength magnetic anomaly where electrons are magnetized while ions remain unmagnetized. A large positive charge is found on the surface in regions where the ions are collected and the electrons are deflected away. The potential on the surface increases with increasing the energy of the incident ions up to values of +20V. However, this is only observed with the dipole moment oriented perpendicular to the surface. When the dipole moment is parallel to the surface, no large positive charges are found. It is likely that electron-electron collisions cause the electrons to be scattered to the surface and neutralize the positive charge. We will discuss the detailed mechanisms and implications for lunar surface charging. Increasing the energy of ions from 50 eV to 1 keV, using an ion source in the future work, is expected to be capable of reproducing the observed much larger positive surface potentials. Our experimental work, along with in situ observations and computer simulations, will help to advance our understanding of lunar surface processes including the formation of unusual albedo features, dust transport and the production and loss of volatiles.

SSERVI-ESF14-048

Author: MICHAEL ZIMMERMAN

ORAL

Dust / Regolith

The solar wind's interaction with a lunar crustal magnetic field: detailed kinetic plasma simulations

We present new 2D simulations of the interaction between the solar wind, the lunar surface, and a km-scale region of isolated crustal magnetization. Results of a simulation to describe the region around local noon, including a subsurface magnetic dipole with a near-surface field strength of 3 _T, show: (1) electron standoff up to 100 m above the surface, (2) protons precipitating onto the surface and creating a >1 kV potential drop and >10 V/m electric field, (3) one or more well-defined, energy-conserving ion jets organized by the strong near-surface electric field, and (4) tenuous populations of ions traveling horizontally along the surface, among many other rich details. This new simulation allows us to characterize the dominant physical processes involved in the solar wind-magnetic anomaly interaction. For example, close attention is paid to the mechanisms that lead to spatial profiles of vertical ion flux and kinetic energy, which are strongly linked to sputtering and space weathering and, hypothetically, lunar swirl formation. These simulations will be useful to inform decisions about future in situ lunar instrumentation.

Author: LINDA BILLINGS

ORAL

Education & Public Outreach

Astrobiology in a changing world: communicating about complex science in a complex cultural environment

Since the turn of this century, NASA's Astrobiology Program has focused increasing attention on communicating with external audiences – scientists, decision makers, the media, students and teachers, and other interested citizens. This focus has led to a number of new and innovative communication, public education, and public outreach activities. As a result, astrobiology has become a "household word." At the same time, though, astrobiology research has grown more complex and thus more challenging to explain to non-experts. This paper will examine some of the Astrobiology Program's 21st century communication, education and outreach activities, such as FameLab Astrobiology, the Astrobiology graphic history series, the NASA-Library of Congress Blumberg chair in astrobiology, a new initiative with the Center of Theological Inquiry and consider their contributions to greater public understanding of the science and the meaning of astrobiology. It also will speculate on possible new directions for communicating about astrobiology in the 21st century.

SSERVI-ESF14-050

Author: LINDA BILLINGS

ORAL

Education & Public Outreach

Communication challenges facing NASA's Near-Earth Object Program and the International Asteroid Warning Network

NASA's Near-Earth Object Program has long faced challenges in communicating clearly and concisely with its various publics about NEO detection and tracking and identification of potentially hazardous NEOs.NASA's Near-Earth Object Program, a research and analysis program of the Planetary Science Division, Science Mission Directorate, was officially established in 1998. The NEO Program operated on a budget averaging $4 million per year from fiscal; year 1998 through fiscal year 2011. In April 2010, the President announced a new goal for NASA: a human mission to an asteroid. The President's fiscal year 2012 budget request included, and Congress authorized, $20.4 million for an expanded NASA NEO observation program. The President's fiscal year 2014 budget request for NASA included $105 million to begin work on an "asteroid redirect" mission, including $40 million for the NEO Program. NASA consequently organized a three-part Asteroid Initiative (http://www.nasa.gov/mission_pages/asteroids/initiative/index.html). The NEO Program's role in this initiative is to provide information on the orbits and characteristics of NEOs that might be accessible for human missions and NEOs that might pose a hazard of colliding with Earth. With Congress, the White House, and other constituencies paying closer attention to NEOs and to planning for planetary defense against NEO impacts with Earth, NASA's NEO Program and the global NEO community are paying closer attention to communication strategy and planning. This paper will review discussions of communication challenges at the 2013 Planetary Defense Conference, the 2014 International Asteroid Warning Network, and the 2013 and 2014 NEO impact tabletop exercises conducted for NASA and the Federal Emergency Management Administration and identify near- and long-term NEO communication needs.

Author: LORA BLEACHER

POSTER

Education & Public Outreach

DREAM2 Education and Public Outreach

The Dynamic Response of Environments at Asteroids, the Moon and moons of Mars (DREAM2) team builds on the work of its predecessor (DREAM), which was established under the auspices of the former NASA Lunar Science Institute, by taking a system-level integrated approach to examining environmentally- driven surface processes common to all airless bodies. The DREAM2 education and public outreach (E/PO) plan builds upon the successful DREAM E/PO program while also bringing DREAM2 and SSERVI content to new and expanded audiences. Based on the results of surveys issued to students who participated in the DREAM E/PO program, it was the direct face-to-face interaction with scientists that they valued the most. These results demonstrate the value of scientist involvement in E/PO efforts. The DREAM2 E/PO plan is designed to allow for increased and sustained interaction between scientists and the audiences DREAM2 will reach.DREAM2's E/PO plan aligns with three of the five goals of the Federal Committee on Science, Technology, Engineering, and Mathematics Education (CoSTEM): 1) Improve STEM instruction; 2) Enhance STEM experience of undergraduate students; 3) Better serve groups historically underrepresented in STEM fields. The DREAM2 E/PO team is also eager to partner with other SSERVI E/PO teams to extend our reach and impact and to share the exciting science efforts of the other institute teams.The keystone component of the DREAM2 E/PO program is a partnership with two academic departments and the on-campus middle school at Howard University (HU), a Historically Black College and University (HBCU) located in Washington, D.C. This partnership spans higher education, formal education, and outreach, and allows DREAM2 and SSERVI-related content to reach students and educators underrepresented in the STEM fields. The best practices gleaned by DREAM2 while working with HU will be shared with other SSERVI teams and the planetary science E/PO community. DREAM2's higher education efforts will provide opportunities for underrepresented undergraduate students in two areas: 1) Students in the HU Department of Physics and Astronomy will engage in authentic NASA research while learning about DREAM2, SSERVI-related content, and NASA and STEM career opportunities, and 2) Pre-service middle and high school science educators in the HU Department of Curriculum and Instruction will receive professional development on DREAM2 and SSERVI-related content, best practices for engaging students in science, and information about NASA and STEM career opportunities via the "DREAM2Explore" professional development workshop series. DREAM2's formal education E/PO efforts will provide in-service educators, including teachers at HU's Middle School for Mathematics and Science (MS2), with professional development, also via the "DREAM2Explore" professional development workshops. Our outreach efforts will focus on interacting with students at MS2 via classroom visits and other opportunities and with the public via participation in large outreach events like International Observe the Moon Night.

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Education & Public Outreach

Crowd sourcing, social media and citizen science

ASTEROID MINING AND SPACE SIMULATIONS WITH CITIZEN SCIENCE AND GAMING. Michelle M. Cadieux, independent on various space teams. Community Safety Programs (MN nonprofit corp) (667 45th Ave NE, Mpls MN 55421, michellecadieuxmba@gmail.com Introduction: Many space companies are trying to find out how the economics of space mining will work. Many of these projects are being completed in simulations like NASA spaceappschallenge.com, Astropreneur.com game, 3d printer simulations like D Space, NASA Dark Side of The Jam, and more. Citizen Science exploration with groups like PongSat, are helping to gather intel on space that will affect exploration in new ways. PongSat has it's first micro-gravity lab now. Crowdfunding has been successful for raising money for projects like NanoSat, LiftPort and others. This paper will aim to explore some of what has been successful, and what hasn't when working on projects aimed at supporting space mining. Hackathons, business start up competitions are a good way to get teams together for a quick weekend to brainstorm ideas. Other competitions like Lunar X Prize and Mars Return Sampling and the NASA Systems Engineering Mars Sampling project for Saylor online university are also good places to find teams working on this. NASA currently has the http://CreateTheFuture.com contest on. Crowdsourcing for volunteers should only be used for nonprofit teams. There have been changes in legislation that crack down on the use of unpaid interns and volunteers for profit making companies. There are also very tricky tax rules about assets acquired for a nonprofit should only be used for a nonprofit and not for profit entities.NASASpinoff.com has always done a good job of showcasing how technologies that have been developed for space are used on earth. Memory foam and other products have been developed, even if velcro, tang, and teflon actually were not. These technologies can help to establish the business case for funding projects, in a climate that is reluctant to fund space projects without a clear ROI. Astropreneurs is a game that hopes to help demostrate the space business model. It was developed at a StartupWeekend with Paul Fuller, and worked on more at NASA's Dark Side of the Jam gaming hackathon with myself and a team, it has continued to grow with developer resources. Michelle Cadieux, MBA. Michelle has been involved with Leeward Space Foundation, LiftPort Space Elevator as the VP, Space StartupWeekend.org, Silicon Valley Space Center org , and more. She has worked in satellites with Lockheed, SolSpike.com rocket powered boot with SolarSystemExpress.com and Pong Sat conference with SVSC, LunarCubes.com, and many other events. She's a supporter of XPrize Team Jurban, and board with Team Prometheus.org.

Author: BROOKE HSU

POSTER

Education & Public Outreach

Remote, In Situ and Synchrotron Studies for Science and Exploration Education and Public Outreach

Through a partnership with the Alan Alda Center for Communicating Science at Stony Brook University, the RIS4E Education and Public Outreach (EPO) team will create a sophomore-level undergraduate science journalism Special Topics course. The RIS4E Special Topics course is being developed in response to a need to create journalists with an understanding of the scientific process. Over the course of a semester, students enrolled in the RIS4E Special Topics course will be exposed to the breadth of scientific investigations being undertaken by the team. Members of the RIS4E science team will be invited to be guest lecturers in the Special Topics Course throughout the semester. Tours of research facilities used by RIS4E researchers are included as part of the course as a way to expose journalism students to scientific research in action. Two students from each class will be competitively selected to accompany members of the RIS4E field team as they conduct research in Hawaii and New Mexico. Students who attend the field excursions will be expected to report on RIS4E team activities. By providing the students with access to RIS4E content, team members, and facilities, students will have an opportunity to learn more about the science of RIS4E, to develop their science journalism skills, and to share the exciting work being done by the RIS4E team with the public. Training the Next Generation of Student AmbassadorsAs part of their research, RIS4E team members will be mentoring 6 undergraduate students per summer. We will provide these students, as part of their research experience, with professional development in best practices in engaging girls in Science, Technology, Engineering, and Mathematics (STEM) content. Additionally, we will be assisting all of the undergraduate interns with identifying education activities in which the interns can participate once they return to their home institutions. Students will then be expected to apply what they learned in their professional development trainings to the educational activities in which they participate. Bringing the Science of RIS4E to the General PublicWe will bring the science of the research team to the public through International Observe the Moon Night (InOMN), an annual public outreach event dedicated to inspiring the public to learn more about the Moon. Since 2010, InOMN has reached over a million people worldwide, and continues to be an exciting way to engage the public in conversations about cutting edge scientific research. RIS4E science will be featured at InOMN events associated with science team members around the country.

Author: ANDREA JONES
POSTER

Education & Public Outreach

FINESSE Education and Public Outreach Program

The Field Investigations to Enable Solar System Science and Exploration (FINESSE) team will conduct a science and exploration field-based research program aimed at generating strategic knowledge in preparation for the human and robotic exploration of the Moon, near-Earth asteroids, and the martian moons Phobos and Deimos. Field investigations in the analog environments of Craters of the Moon National Monument and Preserve in Idaho and at the West Clearwater Lake Impact Structure in northern Canada will address scientific questions pertaining to volcanism and impact science.The FINESSE Education and Public Outreach (E/PO) program will leverage the team's field investigations as well as educational partnerships to share the excitement of lunar, near-Earth asteroid, and martian moon science and exploration locally, nationally, and internationally. The FINESSE E/PO team will coordinate a SSERVI Seminar Speaker Series, offering virtual public presentations designed to share FINESSE science and enhance the public's understanding of NASA's science and exploration goals. These presentations will be advertised on a FINESSE website; through the Lunar List Listserver, a listserv that reaches a community of lunar scientists and enthusiasts; and to NASA Solar System Ambassadors, a cadre of enthusiastic volunteers nationwide who share space science and exploration with their local communities. All talks will be recorded and archived on the FINESSE website. Presentations drawn from this series will also be offered to the NASA Museum Alliance, a network of over 1100 professionals at more than 550 informal education centers nationwide and 60 international centers who incorporate this content into NASA-themed educational activities and exhibits at their institutions.The FINESSE team will also share FINESSE content at venues local to their institutions and field sites. Team members at NASA Ames Research Center will support the Haven House Family Shelter Speaker Series, a program that brings NASA science and technology to underprivileged children near the Center and provides them with opportunities and guidance to pursue careers in STEM fields. Team members at NASA Goddard Space Flight Center (GSFC) will support the Gerald Soffen Lecture Series, a public lecture series that showcases exciting work being conducted at GSFC and by GSFC scientists.At Craters of the Moon, the FINESSE team will partner with the Idaho Space Grant Consortium to include teachers in their field investigations, teaching them about FINESSE science and exploration practices through rich participatory experiences. Team members will also offer to give talks at evening campground programs during field campaigns. The team is committed to reaching out to the community near the West Clearwater Lake impact site as well and has established a partnership with the Centre for Northern Studies (CEN: Centre d'Etudes Nordiques). FINESSE team members will offer to speak at student and community events at a CEN field station that serves Inuit and Cree schools. Additionally, the FINESSE team will support International Observe the Moon Night events at team member institutions and Craters of the Moon, as well as other SSERVI central office outreach efforts, as directed.

Author: ALEXANDRA MATIELLA NOVAK
ORAL

Education & Public Outreach

Lessons Learned on Professional Development for Future Teachers: The Solar System Exploration Pre-service Teacher Institute

The Solar System Exploration Pre-service Teacher Institute is a formal education activity co- led by the JHU Applied Physics Laboratory and the Lunar and Planetary Institute. Funding for this institute is supplied by the APL-VORTICES SSERVI Team (PI Bussey). The institute focuses on engaging pre-service educators, mainly from minority serving institutions, with Solar System science and research. These future middle school STEM teachers will serve as role models to their students. Through these workshops, we are creating a pipeline of opportunities to help future teachers as they pursue their degrees, and will continue partnering with them and serve as resources for them as they encourage their students to pursue STEM interests and careers. This presentation will share the materials developed and lessons learned so far in serving this critical audience.The development of this workshop is being informed by pre-service teacher needs, both from current research on teacher preparation in Earth and space sciences, and from needs expressed by college and university science education faculty who prepare future teachers. The institute also incorporates Nature of Science, explicitly incorporating discussions on what science is, what a theory is, and applying these concepts to the activities and SSERVI research being shared. Additionally, this program connects participants to ongoing research. Participants discuss VORTICES and other SSERVI research directly with our scientists and engineers, and have opportunities to discover how and why research is conducted. Finally, the institute explicitly models (and provide opportunities for participants to practice) educational best-practices such as formative assessment, uncovering and addressing student misconceptions, facilitating learning discussions, wait time, inquiry, and the use of data for mini-research projects.The workshops reflect the NSES for professional development, involving participants in learning and modeling best teaching practices. Each day examines “planetary basics” (orbital characteristics, phases, eclipses) and delves deeply into lunar and small-body science, through a variety of hands-on and inquiry-based activities. At the end of each institute, attendees conduct activities with students to gain experience and familiarity with both the content and the materials. We complement the extensive lunar and asteroidal science classroom materials that APL, LPI, and the NASA education community have created by adding materials based on the science gained by our VORTICES team. We will post the materials to the team’s website and also to the Central Node E/PO site, and materials can also to be integrated into the larger SSERVI formal education initiative. We have initiated a partnership with other SSERVI team E/PO programs on pre-service educator opportunities to leverage our resources and avoid replication.Further information on the Solar System Exploration Pre-Service Teacher Institute is at http://www.lpi.usra.edu/education/workshops/SSE/.

Author: CASSANDRA RUNYON

POSTER

Education & Public Outreach

The art and science of small bodies in our solar system.

To prepare students for a highly visual and tactile workforce, it is imperative that today's classrooms keep up with instructional and informational technologies that are the media of modern life. Engaging students with authentic data sets, real world questions and investigations through a variety of learning strategies offers students and teachers a seamless and coordinated curriculum that is immediately usable in most classrooms across America, particularly those serving at-risk Title I populations. Our SSERVI Education/Public Engagement (EPE) program and activities promote STEAM literacy using the excitement of the success of recent missions and the SSERVI teams. The planned outreach activities and materials highlight not just science, engineering, math, and technology but also how they may be infused with the arts. Examples include, but are not limited to, artistic drawings of the features and changing 'faces' or phases of the moon and morphologic interpretations based on solar incidence angle. In summer 2014, our SSERVI EPE team will work with lead teachers and artists from around the SC Lowcountry to develop arts-infused STEM curricula and tactile graphics to incorporate into a 6-week summer institute for students from underrepresented communities. STEM content will include the origin and evolution of the moon and small bodies in our solar system. We will work with musicians, visual artists, theatre artists, storytellers/creative writers, and dancers. The content will be based on the Next Generation Science Standards and ELA/visual arts standards. At the initial teacher and artist training, the team will share the NASA science and exploration initiatives, the importance of art and writing to problem solving and critical thinking skills, and the need to be proactive in making all materials accessible for ALL learners. Tactile graphics will be used to reinforce content.In South Carolina, among underrepresented communities, there is a 4.5% loss in knowledge retention over the summer. Through this hands-on program, students are expected to increase their knowledge retention, thereby overcoming this learning barrier. In addition to the STEAM curricula, we will develop and share content through stories and other communication media (e.g. tactile books, fiction and nonfiction, songs).

Author: ANDREW SHANER
ORAL

Education & Public Outreach

Center for Lunar Science and Exploration E/PO

The Center for Lunar Science and Exploration (CLSE) E/PO integrates its well-established solar system education programs into the SSERVI portfolio. CLSE E/PO is leading a suite of exciting programs that strengthen the future science workforce, attract and retain students in STEM disciplines, and develop advocates for the exploration of the Moon and asteroids. Specific program efforts focus on the need for high school programs that highlight research experiences emphasizing the nature of science and scientific inquiry and inspire STEM career decisions, and materials for informal education venues to engage the public. The Exploration of the Moon and Asteroids by Secondary Students (ExMASS) program offers secondary students the opportunity to participate in authentic, data-rich, open-inquiry experiences. ExMASS enhances their Earth and space science content knowledge, attitudes toward science and science careers, and understanding of the nature of science and scientific inquiry. The program builds on the CLSE's highly successful High School Lunar Research Projects, a program run under the former NASA Lunar Science Institute. The ExMASS program strengthens the pipeline by articulating explicit paths from high school to higher education science studies. The CLSE E/PO team will create two new asteroid traveling library exhibits to complement the team's current inventory of lunar exhibits. Collectively, these exhibits will engage the public in lunar and asteroid science and exploration by presenting current SSERVI science and exploration topics.In partnership with CosmoQuest, CLSE E/PO will conduct monthly webcasts featuring members of the CLSE science team and other SSERVI science team members. These webcasts will serve to engage the general public, increase advocacy for NASA science and exploration, and provide a means for the general public to enter the NASA pipeline. CLSE E/PO will also host observing events to educate the public about SSERVI, SMD, and NASA science and exploration. These events are theme-based and include theme-aligned, hands-on learning activities for families, opportunities to interact with scientists, short public-focused presentations by scientists, and night sky viewing.Evaluation will be conducted across all CLSE E/PO programs and activities. The purpose of these evaluation activities is to inform the LPI-JSC E/PO Team of the program's successes and to allow the team to make data-driven modifications when necessary.The CLSE E/PO team is also committed to collaborating with SSERVI Central and other SSERVI teams; assisting with educator workshops, sharing SSERVI team science in our programs, collaborating on webcasts and collaborating on events such as InOMN and SMD mission outreach.For more information, please contact the CLSE E/PO lead, Andy Shaner, at shaner@lpi.usra.edu or 281-486-2163.

SSERVI-ESF14-058

Author: KEITH COWING

POSTER

Education & Public Outreach

Lunar Orbiter Image Recovery Project Education and Public Outreach

The Lunar Orbiter Image Recovery Project (LOIRP) was founded in 2007 to recover Lunar Orbiter mission imagery from original analog data tapes recorded as the images first arrived on Earth between 1966-1967. A large part of our effort was generating public visibility for our efforts so as to inform people what were doing but also to generate support for the continued funding of our project. We will discuss the origin of the project, how we engaged the public from the onset, how we translated public interest into support, and how we intend to preserve the output of our project for posterity. We will also discuss the memes that emerged and soon came to characterize our project i.e. use of an abandoned fast food joint, discarded hardware, forgotten engineering, the expertise of retired senior citizens, and how this resonated with the Hacker, DIY, Maker, and citizen science communities. We will also discuss how crowd funding became a crucial part of our project. We will also discuss the implications for other collaborations NASA way wish to consider in the years ahead.

Author: AMALIE SINCLAIR
ORAL

Education & Public Outreach

Treaty Making for Global Exploration

The 1967 Treaty on the Peaceful Uses of Outer Space was formulated more 50 years ago. Since that time many significant technological developments and the emergence of leading potentials propose the requirement for a revisionary basis and for extension of the original treaty consensus into further productivity. This discussion outlines the primary topics of interest, and lines of approach with objectives towards the stable international backgrounds and the enhancement of the Global Space Exploration agenda. The US based treaty initiative may be prepared through placement of a specialized unit at the Library of Congress. Recommendation is for a three phase approach: initial model, policy extension, authorization and public distribution. An early presentation to the international community can made available at UNISPACE IV which is currently under arrangement. Areas which may be addressed by additional clauses and extensions include:1. Sensitive space technologies (nuclear, fusion and laser etc)2. International collaboration (road map development)3. Security interchanges basis (data) and non-proliferation 4. Global data management and utilization (developmental)5. Civil society assurance against misuse of global data 6. Space debris mitigation and removal7. Asteroid mitigation 8. Space tourism and commercial flight safety

Author: MEHDI BENNA

ORAL

Exosphere

Variability of Helium, Neon, and Argon in the lunar exosphere as observed by the LADEE NMS instrument

The Neutral Mass Spectrometer (NMS) of the Lunar Atmosphere and Dust Environment Explorer (LADEE) Mission is a high sensitivity quadrupole mass spectrometer designed to measure the composition and variability of the tenuous lunar atmosphere. The exospheric measurements collected by the NMS instrument cover altitudes that ranged from 4 km to 250 km and spanned all local times and selenographic longitudes. Owing to the LADEE orbit design, low altitude measurements were typically collected over the sunrise terminator while high altitude measurements were collected over the sunset terminator.A sizeable fraction of the NMS observing time was dedicated to tracking the spatial and temporal variability of Helium-4, Neon-20 and Argon-40. While the two first species are of solar wind origin the latter is the result of the radiogenic decay of potassium-40. Observations of the Helium-4 confirms its expected day/night asymmetry with a peak density located between the midnight and the sunrise meridians. The asymmetry of Helium is the result of the difference in accommodation temperature between day and night. Global temporal variability of helium-4 of up to factor 5 were also observed. This variability has a very strong correlation with the flux of solar wind alpha particles that were observed by the 2 ARTEMIS spacecraft. Neon-20 exhibits a comparable day/night asymmetry as Helium with a peak density located prior to sunrise. No temporal variability of Neon-20 was detected for the duration of the LADEE mission. Unlike Helium and Neon, the diurnal variation of Argon-40 follows what was already observed by the Apollo 17 mass spectrometer and can be easily associated with adsorption as the surface cools post-sunset and with rapid desorption at sunrise. NMS has also identified an apparent increase of Argon abundance that is localized over the western maria. This Argon “bulge” was not affected by the diurnal motion of the Moon and its spatial extent and amplitude remained constant for the duration of the LADEE mission.

SSERVI-ESF14-061

Author: ANTHONY COLAPRETE

ORAL

Exosphere

Initial Results from the LADEE Ultraviolet-Visible Spectrometer

The Lunar Atmosphere and Dust Environment Explorer (LADEE) Ultraviolet Visible Spectrometer (UVS) began commissioning activities in orbit around the moon on October 16, 2013. Science observations began October 23, 2013 and continued until minutes prior to the planned disposal of the LADEE SC on April 18, 2014 (UTC). Over the course of the mission the UVS instrument made a series of systematic observations, including lunar limb stares at both terminators and about local noon, targeted activities, including anti-sun sodium tail observations, north/south limb stares, solar occultations, and instrument calibrations. Initial analysis of these observations have resulted in temporal and spatial mapping of key exosphere species, such as sodium and potassium, and the detection of several other species, for example oxygen, titanium and magnesium. UVS finds that sodium abundance varies with lunar phase, the moons position with respect to Earth's magnetotail and with meteoroid showers. Observations in search of dust, including limb and occultation activities, have provided high signal-to-noise spectra which show variations in extinction and scatter. This talk will summarize initial results from the UVS instrument.

Author: DANA HURLEY
ORAL

Exosphere

Propagation of Water in the Chang'e-3 Exhaust Plume from LADEE Observations

Landing a vehicle on the Moon introduces gases from the exhaust plume into the normally sparse lunar exosphere. A robotic lander such as the Chinese Chang'e-3 lander on the surface of the Moon would require burning an estimated 106 g of rocket fuel over ~12 minutes. This rocket exhaust constitutes a 100 times temporary enhancement to the source rate to the lunar exosphere and an increase in the total mass of 10%. It is important to understand the extent and duration of these effects if operations on the Moon become frequent. Whereas the native lunar exosphere is comprised primarily of helium and argon; the rocket exhaust comprises water, carbon dioxide, ammonia, and other HCNO products. The distribution of particles in the lunar exosphere is largely controlled by the interactions between the particles and the lunar surface. Thus, if the propagation of the exhaust vapors can be monitored, it can reveal previously unknown properties of the gas-surface interaction with the lunar regolith. LADEE was in an elliptical, retrograde orbit with an inclination of 22° about the equator. On the day of the Chang'e-3 landing, the Neutral Mass Spectrometer (NMS) acquired data for two orbits prior to the landing and on 4 of the orbits after the landing. Relevant data were also acquired during one orbit on the day following the landing. On each of these orbits, the NMS is turned on just after passing noon lunar local time and acquires in situ measurements of the neutral density about 2000 km from the landing site. Water is detected at 2 sigma above the background level at this location for the three NMS orbits following the landing. We model the release and propagation of the exhaust gases on the Moon and compare to observations in orbit around the Moon from the Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft. Model results are extremely sensitive to the assumed surface interactions. In particular, because the exhaust gases have such a large initial velocity, the degree to which the molecules thermalize on contact with the regolith modulates the subsequent propagation of exhaust gases. Without full thermalization, the bulk of the exhaust gases will escape the Moon on the first hop off of the lunar surface. We present the comparisons between the models and the observations to constrain the amount of thermalization in the model required to agree with the observations. Therefore, LADEE utilizes volatile constituents released during the Chang'e-3 landing on the Moon to determine surface-exosphere interactions of non-native species to the lunar environment. This opportunistic observation adds to the planned scientific return of the LADEE mission.

Author: JASON MCLAIN
POSTER

Exosphere

ENAs Backscattering from Lunar Regolith

When solar wind ions interact with the regolith of airless bodies, some fraction neutralizes and backscatters as energetic neutral atoms (ENAs). ENA imagers onboard Chandrayaan and IBEX observed that ~20% of the solar wind protons are reflected as energetic neutral hydrogen atoms. Lab experiments were performed to simulate solar wind conditions to measure the yield and angular distribution of backscattered neutral hydrogen and helium from Apollo 17 breccia dust. Time-of-Flight analysis was performed to resolve the ENA kinetic energy distribution to model the complex multi-scattering processes involved in the neutralization and subsequent reflection from various surfaces.

SSERVI-ESF14-064
Author: ANDREW POPPE
POSTER

Exosphere

Martian planetary heavy ion sputtering of Phobos and Deimos: implications for the production of neutral tori

The Martian moons, Phobos and Deimos, have long been suspected to be the sources of tenuous neutral gas and dust tori encircling Mars. The neutral tori, first suggested in order to explain observations of interplanetary magnetic field perturbations by the Phobos-2 spacecraft near the orbit of Phobos, have been attributed to many sources, including direct outgassing from Phobos, micrometeoroid impact vaporization, and charged particle sputtering. While direct outgassing has been ruled out based on later measurements, micrometeoroid impact vaporization and charged particle sputtering must operate at some level based on observations at other airless bodies. Previous models have addressed charged particle sputtering of Phobos by the solar wind; however, Phobos and Deimos are also subject to a significant, if temporally variable, flux of heavy planetary ions escaping from Mars, including O^+, O_2^+, and CO_2^+. In this report, we use a combination MHD / test-particle model to calculate the flux of planetary heavy ions to Phobos and in turn, calculate the neutral sputtered flux due to these heavy ions. We show that depending on the solar cycle, the solar wind conditions, and Phobos' location, heavy-ion sputtering of Phobos can generate neutral fluxes up to ten times that from solar wind sputtering. Under such conditions, heavy ion sputtering may be the dominant source of neutrals in the Phobos torus. We discuss implications for the neutral tori and suggest that the MAVEN spacecraft may be able to detect these tori via pick-up ions once in orbit around Mars.

Author: ANDREW POPPE
ORAL

Exosphere

LADEE/LDEX Observations of Pick-up Ion Variability in the Lunar Exosphere

The lunar neutral exosphere is generated by a variety of sources, including thermal and photon-stimulated desorption, micrometeoroid impact vaporization, and charged particle sputtering. The relative importance of each of these production mechanisms should vary by species, location, and external conditions; however, definitive measurements have only been made for some production mechanisms for specific species. The Lunar Dust EXperiment onboard the LADEE mission was designed to investigate the micron and sub-micron sized dust environment around the Moon. Additionally, the instrument has also recorded extensive signatures of the total pick-up ion current around the Moon, originating from photo-ionization and charge exchange ionization of the lunar neutral exosphere. We have compared these measurements to a model of lunar pick-up ion fluxes from the exosphere that includes the presence of neutral species generated by thermal desorption, photon-stimulated desorption, sputtering, and impact vaporization. We present trends identified in the data and discuss implications for our understanding of the lunar exosphere as well as exospheres around other airless bodies throughout the solar system.

Author: KURT RETHERFORD

ORAL

Exosphere

Lunar Volatile Transport in the Exosphere and from Impact Plumes: LRO/LAMP Observing Campaigns Coordinated with LADEE

The Lyman Alpha Mapping Project (LAMP) is an ultraviolet (UV) spectrograph on the Lunar Reconnaissance Orbiter (LRO) that maps the lunar albedo and investigates the lunar exosphere at far-UV wavelengths. Lunar helium atmospheric emissions have been detected remotely with LAMP (Stern et al. 2012), enabling global investigations of its distribution and variability. Helium studies show the abundance varies with solar wind conditions (as expected), including stoppages of helium in-flux during Earth magnetotail transits (Feldman et al. 2012) and a few interesting cases of rapid helium abundance increases (Cook & Stern 2014). LCROSS impact plume observations with LAMP detected H2, CO, Hg, Mg, and Ca (Gladstone et al. 2010), which together with LCROSS observations revealed a much richer mix of volatiles trapped within the PSRs than previously anticipated. GRAIL spacecraft impact plume observations with LAMP detected H and Hg at a high latitude sunlit region (Retherford et al., LPSC, 2013). LAMP's lightcurves of the time evolution of these emissions provide useful constraints to detailed gas plume dynamics models for such impacts reported by Hurley et al. 2012. Tentative detections of argon gas just nightward of the dusk terminator (Cook et al., LPSC, 2014) have a latitudinal distribution that agrees well with model simulations (Grava et al., submitted to Icarus, 2014). Molecular hydrogen is also detected with LAMP (Stern et al. 2013). New, more constraining upper limits to 27 other potential atmosphere constituents have been determined using LAMP (Cook et al. 2013). Lunar Atmospheric and Dust Environment (LADEE) Neutral Mass Spectrometer instrument measures in situ He, Ar, and Ne (Benna et al., LPSC, 2014). The LADEE Ultraviolet-Visible Spectrometer (UVS) routinely measures Na and K emissions, and additionally searches for exospheric dust signatures (Colaprete et al., LPSC, 2014). LAMP searches for similar exospheric dust signatures from dust scattered sunlight and found that upper limits for lunar horizon glow during these observations were at least two orders of magnitude smaller than that inferred from coronal photographs taken during the Apollo 15 mission (Feldman et al. 2014). LADEE's Lunar Dust Experiment (LDEX) occasionally observes bursts of dust particles that are seemingly related to individual meteoroid impacts, but like LAMP, has not detected persistent clouds of fine-grained exospheric dust (Horanyi et al., LPSC, 2014). Analysis of LAMP observations obtained during a series of campaigns coordinated with the LADEE mission is currently underway, and we will present our latest findings. LAMP's view of twilight local time regions from LRO's polar orbit, when combined with LADEE's low (<22.5° N/S) latitude retrograde orbit and instrument set, provides a new global perspective on the lunar exosphere that promises to improve our understanding of volatile and dust transport processes.

Author: KURT RETHERFORD

Exosphere

ORAL

Lunar Volatile Transport in the Exosphere and from Impact Plumes: LRO/LAMP Observing Campaigns Coordinated with LADEE

The Lyman Alpha Mapping Project (LAMP) is an ultraviolet (UV) spectrograph on the Lunar Reconnaissance Orbiter (LRO) that maps the lunar albedo and investigates the lunar exosphere at far-UV wavelengths. Lunar helium atmospheric emissions have been detected remotely with LAMP (Stern et al. 2012), enabling global investigations of its distribution and variability. Helium studies show the abundance varies with solar wind conditions (as expected), including stoppages of helium in-flux during Earth magnetotail transits (Feldman et al. 2012) and a few interesting cases of rapid helium abundance increases (Cook & Stern 2014). LCROSS impact plume observations with LAMP detected H2, CO, Hg, Mg, and Ca (Gladstone et al. 2010), which together with LCROSS observations revealed a much richer mix of volatiles trapped within the PSRs than previously anticipated. GRAIL spacecraft impact plume observations with LAMP detected H and Hg at a high latitude sunlit region (Retherford et al., LPSC, 2013). LAMP's lightcurves of the time evolution of these emissions provide useful constraints to detailed gas plume dynamics models for such impacts reported by Hurley et al. 2012. Tentative detections of argon gas just nightward of the dusk terminator (Cook et al., LPSC, 2014) have a latitudinal distribution that agrees well with model simulations (Grava et al., submitted to Icarus, 2014). Molecular hydrogen is also detected with LAMP (Stern et al. 2013). New, more constraining upper limits to 27 other potential atmosphere constituents have been determined using LAMP (Cook et al. 2013). Lunar Atmospheric and Dust Environment (LADEE) Neutral Mass Spectrometer instrument measures in situ He, Ar, and Ne (Benna et al., LPSC, 2014). The LADEE Ultraviolet-Visible Spectrometer (UVS) routinely measures Na and K emissions, and additionally searches for exospheric dust signatures (Colaprete et al., LPSC, 2014). LAMP searches for similar exospheric dust signatures from dust scattered sunlight and found that upper limits for lunar horizon glow during these observations were at least two orders of magnitude smaller than that inferred from coronal photographs taken during the Apollo 15 mission (Feldman et al. 2014). LADEE's Lunar Dust Experiment (LDEX) occasionally observes bursts of dust particles that are seemingly related to individual meteoroid impacts, but like LAMP, has not detected persistent clouds of fine-grained exospheric dust (Horanyi et al., LPSC, 2014). Analysis of LAMP observations obtained during a series of campaigns coordinated with the LADEE mission is currently underway, and we will present our latest findings. LAMP's view of twilight local time regions from LRO's polar orbit, when combined with LADEE's low (<22.5° N/S) latitude retrograde orbit and instrument set, provides a new global perspective on the lunar exosphere that promises to improve our understanding of volatile and dust transport processes.

SSERVI-ESF14-068

Author: MENELAOS SARANTOS

ORAL

Exosphere

The Na and K content of the Moon's exosphere is limited by the impact vaporization rate

On the basis of scale height considerations, the Na exosphere of the Moon is believed to be provided mainly by photon-stimulated desorption (PSD). Recent measurements of Na ions from the Kaguya ion spectrometer demonstrated that the sodium atmosphere exhibits a dawn-dusk asymmetry and does not peak at the subsolar point as expected from a photon source acting on an unlimited reservoir. These measurements implied that the reservoir for exospheric Na is rapidly depleted on the dayside and must be replenished on the nightside by exospheric migration and/or micrometeoroid impacts. In this view of the exosphere-surface system, impacts vaporize sodium from the subsoil, and the recycled portion of the gas ejecta can be reintroduced to the exosphere by PSD, which acts only on the topmost Angstrom of a grain. Monte Carlo transport simulations of the finite reservoir of Na on the surface performed here demonstrate that the range of impact vaporization rates in the literature suffice to provide the observed exosphere (~70 Na cm-3 near the subsolar point). Besides this proof of concept, three new results are suggested by these simulations. One, the dependence of exospheric sodium with latitude derived from ground based telescopes and Kaguya can be explained by this scheme only if the impact vapor is concentrated at the equator and drops off rapidly at higher latitudes. Two, the location of the peak, 10 degrees off the subsolar point as inferred from Kaguya data, constrains the PSD yield. Third, for a species like K that clearly has a non-uniform distribution on the lunar surface, the simulations demonstrate that if impact vaporization limits the PSD rate, the resulting exosphere will exhibit a periodic variation within each lunation. Therefore, it is possible to probe with Kaguya and LADEE measurements the unknown distribution of Na in the lunar subsoil.

SSERVI-ESF14-069

Author: MENELAOS SARANTOS

ORAL

Exosphere

Constraining refractory elements of the Moon's exosphere from LADEE measurements

We updated our previously published model of transport of refractories in the lunar exosphere (e.g, Mg, Ti, Fe) to infer source and loss mechanisms for these species. New features of this model include: 1) the incorporation of inhomogeneities in surface composition for these elements using Lunar Prospector maps; and 2) the adoption of sputtering maps that describe the exclusion of the solar wind from certain portions of the lunar surface because of magnetic anomalies. Using these maps and a Monte Carlo particle model we simulated the expected variation of these exospheric elements with lunar phase subject to different assumptions for the local time dependence of incident micrometeoroids. Limits to the production by micrometeoroid impacts and sputtering can be obtained by comparing these simulations with the brightness of exospheric emission lines measured by Ultraviolet Spectrometer (UVS) on the Lunar Atmosphere and Dust Experiment Explorer (LADEE).

Author: TIMOTHY STUBBS

ORAL

Exosphere

The Effects of Meteoroid Streams on the Lunar Environment: Observations from the LADEE Mission

Impacts on the lunar surface from meteoroid streams encountered by the Earth-Moon system can result in measurable enhancements in both the lunar atmosphere and dust environment. Here we describe the annual meteoroid streams incident at the Moon during the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission, and discuss their effects on the lunar environment. The LADEE science payload consisted of three instruments: the Ultraviolet/Visible Spectrometer (UVS); the Lunar Dust Experiment (LDEX); and the Neutral Mass Spectrometer (NMS). All three instruments were capable of detecting the effects of an encounter with a meteoroid stream.The Earth-Moon system frequently encounters debris trails from comets and asteroids, which are referred to as meteoroid streams. The meteoroids in these streams have similar velocities and are on near-parallel trajectories, so when they enter the Earth's atmosphere the resulting shower of meteors appears to be emanating from a virtual point on the sky called the radiant. Meteor (and meteoroid) rates vary as a function of the Earth's position in its orbit, with an activity curve that increases to a peak and then decreases. During its time in lunar orbit, the LADEE mission coincided with 18 out of 35 IAU established annual streams. These streams are relatively well characterized and are broad enough that both the Earth and Moon pass through them. Unlike at the Earth, all of the stream meteoroids incident at the Moon will impact its surface and create ejecta clouds and release neutral and ionized species into the exosphere. As stream meteoroids move on near-parallel trajectories we expect to observe asymmetries in their effects on the lunar environment. Therefore, it is necessary to know where the streams are normally incident on the lunar surface (i.e., the locations of the stream radiants in the Moon frame).Based on the Zenith Hourly Rates (ZHR) derived from meteors observed at Earth, one might expect the Geminids (ZHR peak ≈92–120 on 13/14 December 2013) and Quadrantids (ZHR peak of ≈120 or greater on 3 January 2014) to have had the most significant effect on the lunar environment during the mission. (For comparison, the hourly rate for sporadic background meteors is ≈9.5.) While a substantial exospheric response was clearly observed by the LADEE instruments during the Geminids, the apparent response during the Quadrantids was more subdued. One contribution to this difference may have been due to the location of the stream radiant on the lunar surface relative to LADEE's orbit. The Geminids radiant was predicted to be at Selenocentric Solar Ecliptic (SSE) latitude of 10.2°N, which was very close to LADEE's equatorial orbit. Whereas the Quadrantids radiant was much farther poleward of LADEE at SSE latitude of 64.8°N, which could explain the diminished exospheric activity and suggests that the response of the lunar environment to meteoroid streams could be relatively localized.

Author: DIANE WOODEN

Exosphere

ORAL

LADEE UVS Observations of Solar Occultation: Exospheric Dust along lines-of-sight above the Dawn Terminator

Introduction: The Lunar Atmosphere and Dust Environment Explorer (LADEE) is a lunar orbiter launched in September 2012 that investigates the composition and temporal variation of the tenuous lunar exosphere and dust environment. A primary science goal of the LADEE mission is to characterize the dust lunar exosphere prior to future lunar exploration activities, which may alter the lunar environment. To address this goal, the LADEE instrument suite includes an Ultraviolet/Visible Spectrometer (UVS) that has two sets of optics: a limb-viewing telescope, and a solar viewing telescope. The solar viewer foreoptics has six sequential baffles followed by a diffuser that allows UVS to stare directly at the solar disk as the Sun starts to set (or rise from) behind the lunar limb. Solar viewer measurements have very high signal to noise (SNR>500) for 10–26 ms integration times. The 1-degree solar viewer field of view subtends a diameter of ~8 km and samples a column of 400-450 km over the dawn terminator.Occultation Measurements: Solar occultation observations are captured at the lunar sunrise limb, as the LADEE spacecraft passes into the lunar nightside, facing the sun (the spacecraft orbit is near-equatorial retrograde). Spectral collection begins when the solar viewer field of view grazing point is ~40 km above the lunar surface. UVS then continues to collect spectra with the solar viewer pointed directly at the sun, sampling progressively lower altitudes. Sampling continues as the solar disk is partially and then totally occulted by the lunar limb. For this work, UVS occultation measurements for solar viewer fields of view grazing altitudes spanning ~30 – 0 km above the terrain, are analyzed for the signatures of extinction by lunar exospheric dust. Results: For our analyses, the ratio of two spectra (Io and I) defines a time-dependent optical depth. For each occultation activity, Io comes from solar viewer measurements at time in the activity when the limb-viewing telescope is pointed downwards at unlit terrain, corresponding to the dark side of the terminator and solar longitudes of more than about 272 deg. This configuration minimizes scatter from the lunar surface into the telescope foreoptic while the solar viewer foreoptic stares directly at the sun. Spectrum I comes from solar viewer measurements at later times in the activity, down to ~0 km grazing point altitude. A spectral ratio (I/Io) between these two time points (and, correspondingly, field of view altitudes) is then examined to search for dust signatures, which would manifest as differences in spectral absorption from extinction and/or scattering. Our results indicate wavelength-dependent extinction as a function of altitude. We attribute the detected spectral color changes to the presence of sub-micron sized dust grains in the lunar exosphere within specific altitude ranges. We will present and compare our results to previous models[1,2] of the lunar dust exosphere.

Author: JOSHUA CAHILL
POSTER

Geochemistry/Petrology

Determination of synthetic olivine near-infrared optical constants

Mineral optical constants (n, k) are critical for radiative transfer spectral modeling techniques pioneered by Bruce Hapke. Building upon [1, 2], Trang et al. [3] published optical constant regression coefficients for natural and synthetic pyroxenes and natural olivines. The samples used include synthetic pyroxene samples created [4, 5] and natural olivine samples previously characterized by [6-8]. Trang et al. [3]'s analysis suggested the most reliable optical constant measurements were determined using spectra collected by RELAB. This analysis was performed using a combination of MGM and statistical regression analysis techniques. In this way, regression coefficients are determined that allow a computation of optical constants with changing composition using radiative transfer theory. A discovery made during this study was an apparent influence of Mn2+ on absorption strengths of natural olivine spectra [3]. As the abundance of Mn2+ increases and Mg2+ decreases, the compositional relationship between Fe2+-Mg2+ (i.e., Fo-content) becomes a non-linear relationship; the strength of all three of olivine absorptions is curbed when fit, and increases the scatter of k variance with composition. However, neither olivine absorption centers nor widths show any changes in their systematic variation with Fe2+-Mg2+ composition. This discovery was made more prescient recently when [9] effectively constrained optical constants for silicates directly from near-infrared spectra of lunar soils. While this method and optical constants appear to plausibly be more effective, it is unclear exactly how and why lunar mineral optical properties would be so different as to result in significantly underestimating feldspar and overestimating mafic silicates in spectral models of the lunar surface. However, likely influences upon these measurements include trace elements, shock, melting, and devitrification.Here we characterize standard synthetic olivine relative to that of naturally occurring olivine optical constants (i.e., lunar/terrestrial vs. synthetic). We begin by (1) examining synthetic olivine optical properties free of trace element influence and (2) see if we can begin to effectively isolate the influence of Mn2+ on naturally occurring olivine reflectance spectra. The synthetic olivine samples used here were produced by [4, 5] and characterized by [10]. Initial MGM analyses of synthetic olivine appear to be devoid of the absorption strength 'curbing' we observe in the natural olivines for the 0.9, 1.1, and 1.3 _m bands [11]. These synthetic samples are more evenly distributed in terms of the Mg' composition and show less scatter in MGM fitting parameters, especially absorption strength.

SSERVI-ESF14-073

Author: CJ CAREY

Geochemistry/Petrology

ORAL

Machine Learning Tools for Remote-Sensed Spectra from Airless Bodies

Interpretation of remote-sensed spectroscopic data from surfaces of airless bodies relies on a combination of crystal field models and empirical fitting routines to produce estimates of mineralogy, rock types, and space weathering. Current methods for these analyses tend to be computationally cumbersome, sensitive to noise and other factors, and poorly constrained with confidence limits. For problems of unmixing spectral signatures of mixtures of minerals, machine learning methods can yield a more accurate alternative to physical mixing models such as the Modified Gaussian Model. “Whole-spectrum matching” is a technique that enables large-scale analyses of spectra and avoids costly and error-prone peak-fitting and dimension reduction steps. It exploits all available data to compute similarity scores between pairs of spectra. In this presentation, we demonstrate the application of whole spectrum matching to infrared and Raman spectroscopy of minerals and their mixtures.These methods contrast with commonly used peak-fitting and dimension reduction techniques, which solve for a small number of explicit features before computing similarity. Instead, whole-spectrum methods preserve information by avoiding computation of features, making minimal assumptions about data structure and complexity. For example, a peak-fitting algorithm must by necessity threshold the number and quality of peaks reported, which may discard important information when applied to noisy data. Linear dimensionality reduction methods like principal component analysis also impose artificial constraints on data structure, and may become especially harmful in settings with small numbers of training samples.While we do not compute explicit feature representations, preprocessing remains a critical component of whole-spectrum matching algorithms. The entire preprocessing scheme may be broken into several steps of sequentially applied transformations, each of which is applied to all bands of all spectra. These transformation functions must generally satisfy a loose monotonicity requirement, ensuring that the sign of the first derivative of each spectrum will not change, while allowing for changes in the original signal and its higher order derivatives. In this way, relevant properties of spectra are captured without giving undue weight to noise. One unique feature of whole-spectrum analysis is the flexibility it provides regarding spectral data representation. Most existing methods require input in the form of a feature matrix, so all spectra must be resampled to fit a common, fixed-length, one-dimensional vector representation. Whole-spectrum methods eschew this requirement, however, allowing for a more natural “trajectory” representation in whicheach spectrum is stored as an ordered sequence of pairs, denoting the original wavenumber and intensity values. With this trajectory format, no constraints are imposed on the sampling rate or end points of each spectrum. This removes the necessity of resampling altogether, and allows efficient similarity computation for pairs of spectra with large non-overlapping regions. In addition, spectra in vector format usually have thousands of dimensions, which can pose a significant computational challenge. Under a trajectory representation, however, individual points are sparsely connected with only two dimensions per point, which enables computationally efficient matching algorithms.This work supported by the RISE SSERVI.

Author: ARON CORAOR
ORAL

Geochemistry/Petrology

Simulating surface materials: Preparation for the Exploration of Airless Bodies

The spectral data of samples and surfaces of the Moon, Near Earth Asteroids, Phobos, and Deimos will provide invaluable information of the geochemical state of these bodies, necessary for guiding human exploration and sample return. In keeping with the RIS4E goals, we have initiated experimental synthesis of minerals under simulated airless body conditions in order to optimize interpretation of remote sensing data sets and for investigation of the spectral effects of simulated space weathering. Initial efforts have been directed towards assessing the potential for using Fe in plagioclase to distinguish lunar feldspathic terrains, terrains that otherwise are characterized by limited variability in plagioclase composition. For lunar plagioclase, the Fe and Mg contents may rival the abundance of Na. We will report here the results of our efforts to synthesize anorthitic plagioclase with variable Fe contents. The synthesis experiments were designed to grow plagioclase that (i) is in equilibrium with a melt that would stabilize olivine at a lower temperature, but at higher temperature has only plagioclase on the liquidus, (ii) is in equilibrium with metallic Fe, and (iii) is from a melt in which early spinel stabilization has been avoided by the addition of some additional excess silica in the mix (which adds a pyroxene component to the melt). The synthesis experiments involved loading Fe capsules with a well-homogenized mixture of oxides, silicates, and Feo sponge + hematite (to make FeO), placing the capsules (with a constrictor ring to prevent escape of silicate melt) into silica glass tubes and then evacuating these tubes before loading them with enough N2 to provide about an atmosphere of pressure at the synthesis temperature. These tubes were placed in a platform furnace and heated above the liquidus, and cooled to a temperature that remained above the saturation temperature of mineral phases other than plagioclase. Characterization of the material requires consideration of the analytical challenges inherent to low Na compositions and the possibility of secondary Fe-fluorescence when droplets of metallic Fe are present in the plagioclase. Once these materials have been well characterized compositionally and used for Vis-NIR and mid-IR studies, these samples will be used for dust toxicity studies.

Author: M. DARBY DYAR
ORAL

Geochemistry/Petrology

Valence State Measurements of Minerals using X-ray Absorption Spectroscopy

The oxidation state of igneous materials on a planet reflects the degree of oxidation of the magma source region and in some cases the additional effects of magma interaction with the near surface environment and the solar wind. We are developing techniques for pico- and nano-scale interrogation of primitive planetary materials to determine valence state of multivalent elements including Fe, Ti, and V using synchrotron micro-XAS spectroscopy, which makes use of the pre-edge, main edge, and EXAFS regions of absorption edge spectra. Our current work focuses on creating calibration data and protocols for determining valence states in isotropic phases (glass, maskelynite) and anisotropic minerals including olivine, pyroxene, and feldspars. In the latter group of phases, the polarized X-ray beam interacts with each crystal differently as a function of orientation (X-ray pleochroism). Moreover, XAS spectra of geologic samples have been shown to be sensitive to both the abundance of the species in each valence state and the geometry of the coordination polyhedra surrounding them. Thus our calibrations must take into account all three variables that cause changes in the intensities of XAS features: optical orientation, valence state, and polyhedral distortion of each multivalent element site.The key to accurate predictions of valence state lies in the use of multivariate analysis techniques, which take advantage of valuable predictive information not only in the major spectral peaks/features, but in any channel of the entire XAS spectrum. Algorithms for multivariate analysis that “learn” the characteristics of a data set as a function of varying sample characteristics as orientation can then be applied to the spectrum of an unknown. We show here the impressive results of prediction models from one such technique, partial least-squares regression. The models and the resultant predictions improve with each addition of new spectral calibration data, overcoming drawbacks imposed by orientation effects, variable composition, and differences in crystal structures as long as there are adequate calibration standards.

SSERVI-ESF14-076

Author: KYEONG KIM

POSTER

Geochemistry/Petrology

ELEMENTAL ANALYSIS USING A PORTABLE X-RAY SPECTROMETER FOR PLANETARY SURFACE EXPLORATION APPLICATIONS

Active X-ray spectroscopy is commonly used to investigate the elemental composition of planetary surfaces. This technique could be used on a small rover (~20 kg), which is proposed for the prospective Korean lunar mission in 2020. As a first step toward an active X-ray spectrometer (AXS), we have conducted a preliminary scientific investigation using an X-ray spectrometer and an X-ray generator (XRG), which were commercially available from Amptek Inc., to carry out elemental analyses of standard samples and of various rock types. The XRG is a recently-developed technique, and uses a pyroelectric crystal with a broad 8 keV X-ray beam, producing 3*10^8 photons per second. We investigated the X-ray flux stability of the XRG, and it was found to be within +/-10%. This variance is likely caused by an increase in ambient temperature with time. The elemental analysis of four artificial samples using oxides of SiO_2, Al_2O_3, CaO, TiO_2, and Fe_2O_3 and one lunar simulant sample (FJS-1) confirmed a linear relationship between the elemental XRF count ratios and elemental abundance ratio. This result allows a good sample calibration and quantification of elemental abundance for prospective analysis of unknown samples. The elemental calibration curves of Ti/Fe and Ca/Fe ratios provided the elemental abundances of four representative unknown samples of volcanic rock, non-magnetic rock, feldspathic rocks, magnetic rock, and the elemental characteristics of these unknown samples lie on the calibration line. This permits the determination of the elemental ratios, which can be compared with the known elemental abundance information of standard samples. It was observed that finer grain sized samples provided a less scattered linear calibration curve than less uniform grain-sized samples. This study is aiming for both classification and quantification of various types of lunar analog rocks using the elemental analysis by the in-situ X-ray spectrometer, with application to planetary surface exploration conducted by a roving vehicle. This presentation introduces preliminary scientific results and recent technical development of our in-situ XRF analysis.

Author: ANTONIO LANZIROTTI
POSTER

Geochemistry/Petrology

Synchrotron-based microXAFS for probing the oxidation state of extraterrestrial igneous systems

For the vast majority of small extraterrestrial samples that would available from planned sample return missions, traditional macroscopic geochemical techniques are poorly suited. However, advanced synchrotron-based techniques such as microXAFS can be useful to characterize the geochemistry of such small samples, particularly for probing the oxidation state of igneous materials. These measurements can be used to evaluate the degree of oxidation of a planetary magma source region and, possibly, the additional effects of magma interaction with the near surface environment. Synchrotron microXAFS can help constrain the intrinsic oxygen fugacity (fO2) of magma as a direct measure of its oxidation state. We are continuing to develop techniques for pico- and nano-scale interrogation of primitive planetary materials for determining elemental valence state as a proxy for fO2. Multivalent element buffers offer the opportunity to develop oxybarometers based on valence state proxies that span the entire oxygen fugacity range of Solar System evolution. Examples of the systems we are continuing to develop in cosmochemistry include: (1) at the oxidized end of the scale represented by Earth, the Fe valence oxybarometer of terrestrial igneous systems, (2) for Mars under somewhat more reduced conditions, Eu valence oxidation state measurements and (3) under the highly reducing conditions experienced by refractory inclusions (solar gas ~ IW-7), Ti valance state analysis. We have also been developing methodologies for using V valence, species that cover a broad range between oxidizing and reducing conditions. Examples will be discussed.

SSERVI-ESF14-078

Author: ANTONIO LANZIROTTI

POSTER

Geochemistry/Petrology

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Author: MAURIZIO PAJOLA

ORAL

Geochemistry/Petrology

Is Phobos capture origin a priori excluded from its low bulk density?

Flybys of Mars Express confirm the low density of Phobos with the derived value of 1.876 ± 0.02 g/cm3 (Andert et al., 2010, Witasse et al., 2013, Paetzold et al., 2013). Such a value strongly argues in favour of a Phobos formation from a disk of debris (Peale 2007) whether as a remnant of the formation of Mars (Safronov et al., 1986) or as the result of a collision between Mars and a large body (Craddock 1994, 2011; Singer 2007). Within this scenario a low density of the re-accreted material forming Phobos is expected, due to large interior porosity. Thermal emission spectra of Phobos suggest an ultramafic composition with the presence of phyllosilicates and feldspathoids in some regions (Giuranna et al., 2011). Such data would be consistent with formation of Phobos near its current location (1.4-1.7 AU) or in situ (Giuranna et al., 2011).The difficulties in understanding the origin of Phobos arises from the fact that the 0.3-4.0 _m surface spectra taken from multiple areas of the body in more than 43 years of observations (Duxbury et al., 2013), show physical characteristics similar to low-albedo asteroids such as C-type (Masursky et al., 1972, Pang et al., 1980) or D-type (Murchie 1999, Rivkin et al., 2002, Lynch et al., 2007, Pajola et al., 2012). These data argue against an in-situ formation leading to an asteroidal capture scenario: this can be favoured by binary asteroid dissociation (Landis 2009) or by collisional capture in the Martian orbital region (Pajola et al., 2012). Recent data (Schmedemann et al., 2014) suggest an ancient surface age for Phobos of ~ 4.3 – 3.7 Ga, dating back to a period where there was an intensification in the number of impactors in the inner Solar System (Gomes et al., 2005), supporting both the in-situ and the captured scenario. Pajola et al. (2013) presented a mineralogical model composed of a mixture of Tagish Lake meteorite (TL) and Pyroxene Glass (PM80) to explain the surface reflectance of Phobos from 0.4 to 4.0 _m. Starting from the reasonable fit between the proposed model and Phobos spectra, we adopted the weighted TL and PM80 densities to investigate if low bulk density of Phobos could be matched by these components reconciling both inner properties and surface spectra. TL density is available from measurements by Hildebrand et al. (2006), but the density of PM80 (Jager et al., 1994) has not been measured. In order to overcome the lack of density data for the above mentioned pyroxene glass, we have considered density values of different pyroxene glasses from the literature (Karamanov and Pelino, 1999, and Smithsonian Physical Tables 1921) and the density of mafic-rich glasses with VNIR spectra similar to PM80 (Carli et al., 2014). The obtained results will be presented.

Author: PATRICK PEPLOWSKI

ORAL

Geochemistry/Petrology

Abundances of H and major-elements on asteroid 433 Eros: Revisiting the in-situ measurements of the NEAR Gamma-Ray Spectrometer

We have reanalyzed gamma-ray measurements taken on the surface of asteroid 433 Eros by the Near-Earth Asteroid Rendezvous (NEAR) spacecraft. This dataset represents the first in-situ measurements acquired from the surface of an asteroid, and it provides important insights into the composition of near-earth asteroids. Our reanalysis, which utilizes improved knowledge of the detector response and gamma-ray production physics, has allowed us to link the composition of Eros to the LL-chondrites. Additionally, comparisons of Fe gamma rays from neutron inelastic scatter and neutron capture reactions provide constrains on the hydrogen content of the regolith. Our H abundance value of 0 to 300 ppm represents the first in-situ measurement of the hydrogen content of an asteroid. This value is lower than the average H content for LL-chondrite meteorites, both finds and observed falls, and suggests that hydrogen may be depleted in near-surface materials on Eros. This is consistent with observations of the depletion of the moderately volatile element S by the NEAR X-Ray Spectrometer. Depletion of volatile elements on asteroids has implications for human exploration and resource utilization of near-earth asteroids.

Author: SARA PORT

POSTER

Geochemistry/Petrology

Quantifying hydroxyl radical production from pulverized olivine with Electron Spin Resonance (ESR) spectroscopy

Recent research has demonstrated that when several different types of minerals, such as olivine, augite, and quartz, are pulverised in the laboratory, reactive oxygen species, or "ROS", are produced, including hydrogen peroxide, superoxide, and hydroxyl radicals. These reactive compounds can be hazardous to humans, as they are highly reactive with organic matter. This makes ROS production an important phenomenon to study in an effort to assess the potential health impacts to astronauts sent to other planetary bodies within our solar system, where fine-grained, pulverized mineral dusts are found in abundance. These mineral dusts are thought to be produced by meteorite impacts into planetary surfaces as well as mechanical weathering by aeolian processes on dry planets with atmospheres, such as Mars. It is relatively unknown how much of these reactive compounds are produced, or how much pulverization is required in order to yield a measurable amount of ROS. In order to determine this, we are performing research on pulverized olivine, an abundant mineral on basaltic planetary bodies such as the Moon, Mars, and asteroids, and which is known to produce reactive hydroxyl radicals.In order to accurately quantify hydroxyl radical production, we use ESR spectroscopic measurements of the stable free radical compound Tempol (4-hydroxy-2, 2, 6, 6-tetramethylpiperidin) to generate linear calibration curves that permit quantification of radical concentrations as low as 1 micromolar. For our experiments, we grind olivine using a planetary ball mill with an agate grinding bowl and agate grinding balls. We then expose the ground olivine to a dilute solution of the spin trapping compound 5, 5-Dimethyl-1-Pyrroline-N-Oxide, or DMPO. OH radical is produced as a by-product of reactions between pulverized olivine and water, but because OH radical is highly unstable, it is necessary to use DMPO to "trap" or stabilize the radical as a DMPO OH-radical adduct for measurement by ESR. The slurry of DMPO, water, and olivine are allowed to react for a prescribed period of time while being agitated, and the slurries are then centrifuged to separate the solids and liquids. The supernatant is then measured by ESR and can be quantified using a Tempol calibration curve.Our initial measurements have verified that OH-radical is indeed produced by pulverized olivine, and furthermore, that the combination of ESR spectroscopy, Tempol calibration, and DMPO spin trapping should produce robust, quantitative measurements of mineral reactivity. We will report on our quantitative assessment of olivine reactivity, and our ongoing work will explore the reactivity of olivine and other relevant mineral phases in effort to protect future explorers visiting planetary surfaces in the Solar System.

SSERVI-ESF14-082

Author: MELINDA RUCKS

POSTER

Geochemistry/Petrology

MID IR Optical Constants of Orthopyroxenes

Orthopyroxenes are common rock forming minerals that are present on many planetary bodies as well as meteorites and cosmic dust. The presence of these minerals can give implications to the petrogenic history of these planetary bodies. Optical constants, n and k, are essential inputs into radiative transfer models which are used in remote sensing techniques. [1,2] While optical constants have been determined for orthopyroxenes with high Mg content, Fe rich orthopyroxenes have not been studied as extensively. [3] The goal of this research is to determine the optical constants of orthopyroxenes ranging in composition along the enstatite-ferrosilite solid solution, to gain a more comprehensive list of these values. Specular reflectance spectra, in the range of 250-4000 cm-1, were obtained for several oriented single crystal samples at three crystallographic orientations for each sample. Optical constants, n and k, were then derived through modeling of measured spectra using the Matlab lsqcurvefit function. Preliminary research on natural Mg rich orthopyroxene samples has shown comparable results to previous studies. Future work will apply this method to orthopyroxene samples with higher iron content.[1] Arnold, J.A. et al (2013) (under review), [2] Glotch, T.D. and Rossman, G.R. (2009) Icarus, [3] Jäger, C. et al (1998) Astron. Astrophys.

SSERVI-ESF14-083

Author: MARTIN SCHOONEN

ORAL

Geochemistry/Petrology

Reactive Oxygen Species Generation by Lunar Simulants

With the eventual deployment of human explorers to near-Earth, airless planetary bodies and the establishment of a long-term manned research site on the Moon or other Target Bodies, it is inevitable that humans will be exposed to local mineral dust. Repetitive inhalation exposure to mineral dust in industrial settings is considered an occupational health risk, which can lead to various lung ailments. While daily and lifetime exposures for human explorers are expected to be far less than for those working a lifetime in industrial settings, the mineral dust that human explorers will likely be exposed to is expected to be highly reactive due to the presence of unsatisfied surface bonds and nanophase metallic iron. Mineral inhalation exposure can lead to inflammation, cytotoxicity (i.e., toxicity to cells), genotoxicity (i.e, damage to DNA), and fibrosis. One of the factors possibly contributing to the toxicity of a material is its ability to generate Reactive Oxygen Species (ROS). ROS are oxygen-containing species are chemically reactive molecules containing molecular oxygen. In vitro, the step-wise reduction of molecular oxygen leads to the formation of superoxide radical (O2*-), hydrogen peroxide (H2O2) and hydroxyl radical (OH*). Hydroxyl radical is by far the most damaging to biomolecules. In vivo, the immune system triggers the formation H2O2 when challenged with a foreign substance. Cellularly-derived H2O2 can react with transition metal-containing minerals to generate OH* via the Fenton reaction. In this contribution, we report results of an ongoing study to determine the spontaneous generation of OH* upon dispersion of lunar simulants in water as well as through conversion of H2O2. The OH* formation was quantified using both Electron Spin Resonance (ESR) spectroscopy and molecular probes. ESR combined with spin trapping using 5,5-Dimethyl-1-pyrroline N-oxide (DMPO) provides an assessment of the initial formation of OH*, while the molecular probe provides insights into the formation of OH* over periods up to 12 days. A suite of lunar simulants, including JSC-1A and NU-LHT-2M , were investigated. We have evaluated the spontaneous formation of OH* as a function of mechanical stress by hand grinding as well as the formation of OH* through the interaction between H2O2 and simulant. We also plan to evaluate the effects of UV irradiation and dehydroxylation on these simulants as well as to determine the formation of OH radicals upon the dispersion of treated and untreated simulants in simulated lung fluid. ESR spin trap results thus far indicate a modest increase in the amount of OH* released as a result of mechanical stress. This is likely associated with the formation of broken bonds at mineral surfaces. Additional studies are needed to determine if this treatment imparts reactivity that lasts for more than a few minutes. Experiments with untreated simulants and H2O2 using a molecular probe showed no formation of OH* within 286 hours.

Author: ALEXANDER BASILEVSKY

POSTER

Geology

Survival times of meter-sized rock boulders on the surface of bodies without atmospheres

We consider the issue of the survival times of meter-sized rock boulders on the surface of bodies without atmospheres. The approach we use was tested in our recent work1 and it is based on thee consideration of the spatial density of boulders on the rims of small lunar craters of known absolute age. In that study1 it was assumed that major factor and process involved in boulder destruction is catastrophic disruption by meteorite impacts. The potential role of diurnal temperature cycling2 was mentioned but not studied. In this analysis, we review the lunar results as a staring point and we then discuss the potential role of thermal cycling. We show that it is less important then disruption by meteorite impacts. Finally, we analyze the meteorite bombardment environment in terms of projectile flux and velocities and based on this we estimate survival times of meter-sized boulders on a range of bodies without atmospheres.1Basilevsky et al. (2013)2Delbo M. et al. Thermal fatigue as the origin of regolith on small asteroids. Nature, 508, 233-236 (2014).

Author: KRISTEN BENNETT

ORAL

Geology

Inferred Variable FeO Content in Medium-Sized Lunar Pyroclastic Deposits from LRO Diviner Data

Lunar pyroclastic deposits (LPDs) are low albedo features that mantle underlying terrain (Gaddis et al. 1985). They are high priority targets for science and exploration as they are believed to originate from and therefore reflect the composition of the deep lunar interior (NRC, 2011). They are also the best potential resource of oxygen out of any Apollo samples (Allen et al. 1996). Historically, LPDs have been divided into regional versus local categories (Gaddis et al. 2003). The large (>1000 km2 area) regional deposits are deeply sourced (>400 km deep) and result from fire fountaining. Small (<1000 km2) local deposits are thought to result from Vulcanian eruptions in which magma is slowly emplaced beneath the surface until enough volatiles exsolve and the high pressure causes an explosion. Bennett et al. (2013) identified a local deposit (674 km2 area) that may have resulted from both Vulcanian activity and fire fountaining. This deposit potentially represents a new intermediate class of LPDs that straddles the interface between the two formation mechanisms. The deposit also exhibits the highest inferred FeO wt.% of any known lunar glass. In this work we investigate the inferred FeO abundances of other medium-sized deposits to characterize this potential new class of deposits and understand the magnitude of variations in inferred FeO among pyroclastic deposits.
We use the method of Greenhagen et al. (2010) to calculate the wavelength of the Christiansen Feature (CF) from Lunar Reconnaissance Orbiter Diviner Lunar Radiometer instrument thermal-infrared observations for four medium-sized deposits. From the CF values, we estimate each deposit's FeO abundance using the method of Allen et al. (2012). The four LPDs that we examined (Oppenheimer South, Beer, Cleomedes, and J. Herschel) all have average CF values from 8.22-8.28 microns, corresponding to FeO abundances of ~10-15 wt.%. All of these values are within the range and uncertainties of FeO abundances measured in Apollo samples. As previously identified, the Oppenheimer South deposit exhibits an area of enhanced CF values (8.49 microns) that, if the methods of Allen et al. (2012) can be extrapolated, correspond to a highest observed ~30 wt.% FeO. Moon Mineralogy Mapper near-infrared spectra indicate that this area is glass-rich as opposed to olivine-rich. While we are still investigating the nature of the high CF wavelength in Oppenheimer South, spatially-resolved observations there and (to a smaller degree) in our other study sites, shows that FeO wt.% can vary within LPDs. Thus, obtaining only the average FeO abundance over a large area may not be adequate to understand global variation. The magnitude of Oppenheimer South's CF variability, if due to actual surface variations rather than calibration artifacts or spectral mixing, could indicate that it is a unique deposit and not part of a new mid-sized class of deposits. The higher value could be a result of its location within the South Pole Aitken Basin and exsolution of more deeply sourced magma due to the thin crust there.

Author: JACOB BLEACHER

Geology

ORAL

Remote, In Situ, and Synchrotron Studies for Science and Exploration (RIS4E) Field Campaigns

The RIS4E team will conduct yearly geologic field campaigns as a means of evaluating instrument design and best practices for their use during future HEOMD exploration of Target Bodies. The design and use of portable instruments that provide real-time analytical data to astronauts and a science team have been largely unexplored despite a heritage of useful analog tests. To address this identified need for future SMD-HEOMD exploration, we will perform three main tasks that involve field geology at the December 1974 (D1974) flow on K_lauea Volcano, HI, and the Potrillo Volcanic Field (PVF), NM. Field work at these sites will use currently available portable analytical science instruments to provide new scientific insights into the volcanic and igneous development of these lunar analog volcanic terrains, pursuing three tasks: 1) characterizing precise field location, or topography, and subsurface structure, 2) characterizing geochemical and mineralogical details that are not decipherable from remote measurements, and 3) evaluating results to provide insights into the design and use of portable/handheld SMD instruments during HEOMD exploration of SSERVI Target Bodies.The field sites selected for our field campaigns enable scientific studies of concepts relevant to planetary exploration. At the Hawaiian lava flow field we will test if sinuous channels can form when preferred pathways drain from within an active sheet flow. Such channels or rilles would lack levees and display deep channels with steep walls. Such a process could explain lunar rille formation without the formation of lava tubes, thereby lacking radiation safe havens. At the New Mexican lava flows the RIS4E team will characterize pits that are associated with lava tubes, and those that formed within inflated sheet flows. At both sites the team will use precise surface location information (topography) and knowledge of subsurface structure (Ground Penetrating Radar) to provide new scientific insights that help differentiate tube-related from sheet inflation-related pit formation as a means of better interpreting the lunar volcanic history and identifying radiation safe havens. Thus, the RIS4E team will determine best approaches to coupling surface topographic data with GPR data to best characterize the near-surface structure of SSERVI Target Bodies.High resolution spectral observations of the Moon and studies of lunar meteorites show unique lithologies that were not observed at coarser resolution remote observations. Similarly, laboratory analyses of samples collected from locations that are identified as spectral end member units in the D1974 Hawaiian lava flow show significant spectral variability, suggesting that the remotely derived spectrum was better represented as an average of the individual samples collected rather than a match to any single sample. We will characterize geochemical and mineralogical variability across both field sites using currently available, portable instruments. This will enable the RIS4E team to evaluate best practices for developing and incorporating hand-held SMD geochemistry/mineralogy instrumentation into future HEOMD sampling strategies for Target Bodies.

Author: JOSHUA CAHILL
POSTER

Geology

SURVEYING THE SOUTH POLE-AITKEN BASIN MAGNETIC ANOMALY FOR REMNANT IMPACTOR METALLIC IRON

For decades it has been known that portions of the lunar crust are strongly magnetized [1-4]; yet the origin of magnetization is not understood. Difficulties discerning a source for these anomalies begin with most of them having no consistent association with geologic structures. Impact basins and ejecta, and antipodes are geologic structures that sometimes associate with magnetic anomalies [5], but most are weak relative to the global dynamic range. Further, many of these same structures do not show magnetic anomalies. It is also difficult to reconcile the strengths of many of these anomalies with lunar samples, as most lunar materials are weakly magnetic relative to terrestrial materials. Magnetic measurements of mare basalt and pristine highlands rock show weaker magnetism relative to mid-ocean ridge basalts (~3 orders of magnitude) [6]. Another complication is the mineralogy of lunar magnetic anomalies is not rigorously constrained. As a result, it is difficult to discern if the magnetization is derived from crystallization or from impact shock [7, 8].Wieczorek et al. [9] suggest that magnetic anomalies on the southern farside of the Moon are attributable to remnant metallic iron from the impactor that created South Pole-Aitken basin (SPA) [9]. They argue that the distribution of modeled projectile materials roughly coincide with the distribution of magnetic anomalies near the northern rim of SPA. Wieczorek et al. [9] note that chondritic projectiles are approximately two times more magnetic than average lunar crustal materials. If the SPA-forming projectile were similar to an undifferentiated chondrite, then the thickness of the ejecta needed to account for the magnetism of materials north of SPA would only need to be a few hundred meters thick. This thickness could be less if the projectile were differentiated into core, mantle, and crustal components. We evaluate this hypothesis combining Lunar Prospector Gamma Ray Spectrometer (GRS) and Clementine reflectance (CSR) FeO products. Our results are ultimately inconclusive. Delta FeO (i.e., GRS-CRS) is higher north of SPA as observed by GRS and might suggest detection of remnant metallic iron. However, excess GRS FeO is evenly distributed throughout the farside highlands. Any remnant high-Fe materials would need to cover the farside highlands in ejecta, and then avoid being covered with a subsequent 10 cm of regolith from impact processes. Furthermore, _FeO and magnetic anomalies are not spatially correlated and do not show corresponding dynamic intensity ranges. Ultimately, due to the old age of SPA and subsequent impact mixing, it may be that any magnetic materials are now too deep to be detected by either instrument. Acknowledgments: Supported by NASA LASER grant NNH09AL71I.

Author: KERRI DONALDSON HANNA

POSTER

Geology

Thermal Infrared Studies of Lunar Soils: Characterizing Spectral Effects due to Simulated Lunar Conditions and Packing

Apollo soils [e.g. 1-3] as well as basaltic rocks [4] have been well-characterized across the visible- to near-infrared wavelengths including the effects of particle size, mineralogy, mineral chemistries, ilmenite content and space weathering on their spectra. These laboratory analyses provided ground truth to remote sensing observations from Earth-based telescopic observations and spacecraft observations like those from Clementine, Galileo, Lunar Prospector, SELENE, and Chandrayaan-1 as well as providing key insights into the composition and evolution of the lunar surface. The Diviner Lunar Radiometer, a thermal infrared (TIR) radiometer onboard the Lunar Reconnaissance Orbiter, has been orbiting the Moon since 2009. Quantitative analyses of these multispectral TIR data have required the characterization of Apollo samples across TIR wavelengths. The near-surface vacuum environment of airless bodies like the Moon creates a thermal gradient in the upper hundred microns of regolith. Lab studies of particulate rocks and minerals as well as selected lunar soils under vacuum and lunar-like conditions have characterized the effects of this thermal gradient on TIR spectral measurements [e.g. 5-9]. Such lab studies demonstrate the high sensitivity of TIR emissivity spectra to environmental conditions under which they are measured. Furthermore, TIR lab studies have demonstrated the spectral effects of packing on TIR spectral measurements [e.g. 5,10].In this work, an initial set of TIR emissivity measurements of bulk lunar soil samples will be made in the Asteroid and Lunar Environment Chamber at Brown University [11] and the Simulated Lunar Environment Chamber at the University of Oxford [8]. In each chamber, the lunar environment is simulated by: (1) pumping the chambers to vacuum pressures (<10-3 mbar), which is sufficient to simulate lunar heat transport processes within the sample, (2) cooling the chambers with liquid nitrogen to simulate the cold space environment that the Moon radiates into, and (3) heating the samples from below, above, or both to set up thermal gradients similar to those experienced in the upper hundreds of microns of the lunar surface. These laboratory measurements of bulk lunar soil samples will be compared with Diviner data to understand: (1) how to accurately simulate conditions of the near-surface environment of the Moon in the lab and (2) the difference between returned samples and undisturbed lunar soils in their native setting. Both are integral for constraining the composition and physical properties of the lunar surface from current and future TIR datasets.

Author: ABIGAIL FRAEMAN

ORAL

Geology

Compositions of Phobos and Deimos: The View from Visible to Near Infrared Spectroscopy

The compositions of Mars' moons, Phobos and Deimos, are a direct indicator of the mechanism that formed them. One of the longstanding questions of planetary science is whether the moons formed in situ around Mars, either through co-accretion or giant impact, or if they are captured asteroids originating from elsewhere in the solar system [1]. The key to unlocking this mystery will be to determine whether the moons are composed of materials native to the Martian system or if they are made of something that could only have arrived from another location [2]. Disk-resolved, visible to near infrared hyperspectral observations of Phobos acquired by OMEGA at a range of lighting and viewing geometries are fit with a Hapke photometric function to solve for the single particle phase function. This knowledge is used to derive single scattering albedos of CRISM and OMEGA Phobos and CRISM Deimos observations, which can be projected to any viewing geometry for direct comparison with laboratory spectra. Fe electronic absorptions diagnostic of olivine and pyroxene are not detected. A broad absorption centered on 0.65 μm within the red spectral units of both moons is seen, and this feature is also evident in telescopic, Pathfinder, and Phobos-2 observations of Phobos. A 2.8 _m metal-OH combination absorption on both moons is also detected, and this absorption is shallower in the Phobos blue unit than in the Phobos red unit and Deimos. The strength, position, and shape of both features are similar to absorptions seen on low-albedo primitive asteroids. Two end-member hypotheses could explain these spectral features: the presence of highly desiccated Fe-phyllosilicate minerals indigenous to the bodies, or Rayleigh scattering and absorption of small iron particles formed by exogenic space weathering processing, coupled with implantation of H from solar wind [3]. Both end-member hypotheses may play a role, and in situ exploration will be needed to ultimately determine the underlying causes for this pair of spectral features. Phobos' and Deimos' low reflectances, lack of mafic absorption features, and red spectral slopes are incompatible with even highly space weathered chondritic or basaltic compositions. These results, coupled with similarities to laboratory spectra of Tagish Lake (possible D-type asteroid analog) and CM carbonaceous chondrite meteorites, show that Phobos and Deimos have primitive, carbonaceous-chondrite like compositions. If the moons formed in situ rather than by capture of primitive bodies, primitive materials must have been added to the Martian system during accretion or a late stage impact [4]. References: [1] Burns, 1992, Mars, Univ. Arizona Press, [2] Murchie et al., 2014, Acta Astronautica, 93, 475-482, [3] Fraeman et al., 2014, Icarus, 229, 196-205, [4] Fraeman et al., 2012, JGR, 117.

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Author: W. BRENT GARRY

ORAL

Geology

The Formation of Pits in Volcanic Environments: Analogs and Lessons for the Future Planetary Exploration

Introduction: Martian and lunar pits with overhanging ledges might be connected to caves or lava tubes, and these caves could be used as safe havens for astronauts as protection from high radiation Solar events. Terrestrial pits found in volcanic terrains can form through several scenarios and still appear morphologically similar to the Martian and lunar pits. However, lava flow inflation (among other methods) also form pits with overhanging ledges that appear to connect to subsurface void space. Yet, field observations show that inflation pits do not connect to caves.Analogs: We have conducted field work in basaltic environments in Hawaii, New Mexico, and Idaho and observed pits at each site. Not every pit we have observed leads to an extensive, interconnected system of tubes or void space. For example, within the McCartys lava flow circular pits form within the inflation plateaus and have overhanging ledges, rubbly bottoms, but drained-out tube systems are not present. In other terrains (e.g., Kilauea Southwest Rift Zone (SWRZ), HI; Cerro Rendija, NM), even though a lava tube is present beneath the surface, access to the tube has been blocked by debris. Ideal field sites (e.g. Mauna Loa SWRZ) exhibit visible layering in the upper walls and an accessible tube system. Exploration: The discovery of subsurface voids on both the Moon and Mars could lead to potentially ground breaking missions. LiDAR can provide precise measurements of pit morphology and Ground Penetrating Radar (GPR) can provide reconnaissance of the subsurface around the pit. NASA has funded a study of volcanic pits via the SSERVI RIS4E team over the next 5 years to investigate this issue. Prior to any mission (human or robotic), it will be important to understand the geologic context of these pits. Differentiating tube or rille-fed from sheet-fed flows is crucial for developing informed predictions of which pits might be linked to tubes or caves. Furthermore, assessing the surface and subsurface expressions of pits and caves (lava tubes) is critical for future Human Exploration Operations Mission Directorate (HEOMD) strategies that might include these geologic features for radiation protection.

Author: BENJAMIN GREENHAGEN

ORAL

Geology

Compositional Ground Truth for the Diviner Lunar Radiometer: Comparing Apollo Sites and Soils

Apollo landing sites and returned soils afford us a unique opportunity to "ground truth" Diviner Lunar Radiometer compositional observations, which are the first global, high resolution, thermal infrared measurements of an airless body. The Moon is the most accessible member of the most abundant class of solar system objects, including all SSERVI target bodies. Additionally, the Apollo samples returned from the Moon are the only extraterrestrial samples with known spatial context. Here we compare Diviner observations of Apollo landing sites and compositional and spectral laboratory measurements of returned Apollo soils.Diviner, onboard NASA's Lunar Reconnaissance Orbiter, has three spectral channels near 8 µm that were designed to characterize the mid-infrared emissivity maximum known as the Christiansen feature (CF), a well-studied indicator of silicate mineralogy. It has been established previously that thermal infrared spectra measured in simulated lunar environment (SLE) are significantly altered from spectra measured under terrestrial or martian conditions, with enhanced CF contrast and shifted CF position relative to other spectral features. Therefore only thermal emission experiments conducted in SLE are directly comparable to Diviner data. Here we present data collected at the University of Oxford Simulated Lunar Environment Chamber (SLEC) and JPL's Simulated Airless Body Emission Laboratory (SABEL).With known compositions, Apollo landing sites and soils are important calibration points for the Diviner dataset, which includes all six Apollo sites at approximately 200 m spatial resolution. Differences in measured CFs caused by composition and space weathering are apparent in Diviner data. We find that analyses of Diviner observations and SLE measurements for a range of Apollo soils show good agreement, while comparisons to thermal reflectance measurements under ambient conditions do not agree well, which underscores the need for SLE measurements and validates the Diviner compositional measurement technique.Diviner observations of Apollo landing sites are also correlated with geochemical measurements of Apollo soils from the Lunar Sample Compendium. In particular, the correlations between CF and FeO and Al2O3 are very strong, owing to the dependence on the feldspar-mafic ratio. Our analyses, an extension of earlier work, support findings that Diviner data may offer an independent measure of soil iron content from the existing optical and gamma-ray spectrometer datasets.

Author: JAMES HEAD, III

ORAL

Geology

Lunar Geoscience: Key Questions for Future Lunar Exploration

The last several decades of intensive robotic exploration of the Moon has built on early Apollo and Luna exploration to provide fundamental knowledge of Earth's satellite and an excellent perspective on the most well-documented planetary body other than Earth. This new planetological perspective has raised substantial new questions about the nature of the origin of the Moon, its early differentiation and bombardment history, its internal thermal evolution, the production of its secondary crust as exemplified by the lunar maria, and tertiary crust as potentially seen in steep-sided domes and impact melt differentiates, the abundance of interior volatiles and their role in volcanic eruptions, and the abundance of surface volatiles and their concentration in polar regions. On the basis of this new information, a series of specific outstanding geoscience questions can be identified that can serve as guides for future human and robotic exploration. These include: 1) What is the nature and abundance of impact melt seas and what rock types do they produce upon differentiation and solidification? 2) Where are lunar mantle samples located on the lunar surface and what processes are responsible for placing them there? 3) What processes are responsible for producing the silica-rich viscous domes, such as those seen at Gruithuisen? 4) What are the volatile species involved in the emplacement of lunar pyroclastic deposits and what clues do they provide about deep magmatic volatiles and shallow volatile formation processes? 5) How do we account for the differing characteristics of regional dark mantling pyroclastic deposits? 6) When did mare basalt volcanism begin (earliest cryptmaria) and how and where is it manifested? 7) Was there extensive volcanism and resurfacing prior to mare basalt volcanism; if so, what is its origin and how is it manifested? 8) Are there other shallow magmatic intrusions besides floor-fractured craters, and if so, what is their origin? 9) What clues can we derive from the geology and gravity structure of floor-fractured craters concerning the modes of emplacement and magmatic evolution of shallow intrusions; does differentiation and volatile build-up take place? 10) What are the factors that explain the formation of complex craters, peak-ring basins and multi-ring basins? 11) What are the ages of key multi-ring basin impact melt sheets and how do they help to determine lunar impact chronology and flux? 12) How can lunar crustal density and thickness structure revealed by GRAIL be related to geological impact, magmatic and tectonic processes? 13) What is the origin, distribution and mode of emplacement of polar and circum-polar volatile deposits? 14) What is the origin of central peaks and their often unusual mineralogy and how do we account for the evidence for heterogeneous melt composition and structure? These and other major geoscience questions form the basis for robust and exciting future international robotic and human exploration and sample return missions. A series of candidate sites of interest are identified that can address these questions.

Author: SCOTT HUGHES

Geology

ORAL

Combined Geomorphic and Petrologic Models of Lava Flow Surfaces, Pyroclastic Ejecta and Volcanic Stratigraphy as Planetary Analogs

Geomorphology of volcanic features, widely used to interpret eruptive history and magma generation, often lead to extended evaluations of planetary body evolution. Investigations typically based on close field observations and/or remote sensing imagery, are used in conjunction with geochemical and petrographic information to make such broad interpretations.Research by the FINESSE team (PI Jennifer Heldmann) aims to decipher and quantitatively model volcanic features that represent a wide variety of morphological types at Craters of the Moon National Monument and Preserve (CRMO), and immediate surroundings on the eastern Snake River Plain (ESRP). The region was selected for the variety and relative freshness of the surfaces (~2 – 15 ka eruptions) and close apparent relation between composition and geomorphology, ranging from basalts with pahoehoe and a'a surfaces to evolved trachyandesites with block flow surfaces. Surface types often change within a single flow over a relatively short distance. Comparison to similar fresh features in Hawai'i in conjunction with the RIS4E team (PI Timothy Glotch), and other regions of active volcanism will enable a broader assessment of myriad complexities that go beyond the well-known classification and sub-classifications of lava flow types, and possibly lead to more detailed comparison with impact-generated melts and their accompanying lava flows.Our preliminary research focuses on the classification of morphotypes of lava flow surfaces based on close field examination, hand-held and UAV-mounted imagery, sub-cm LiDAR, and differential GPS to quantify models of surface roughness and the spacing of irregularities in relief, thickness, and flow unit forms. Our study also aims to investigate, by similar means, pyroclastic fields, tephra-coatings on lavas, large "rafts" of congealed tephra blocks carried several km on lava flow surfaces, and blocks (positions and masses) ejected by volatile-related explosive eruptions. Geomorphic models are being addressed in conjunction with geochemical and petrographic attributes. The intention is to produce quantifiable models that can be used to interpret features on SSERVI target bodies involving various exploration techniques (robotics, remote sensing, on-site visits by astronauts).Preliminary tasks address (1) classification and spatial distribution of volcanic constructs; (2) rock types, dimensions, volumes, and relative proportions comprising each construct; (3) ejecta distribution at explosive pit craters; and (4) the variability in slope and surface roughness of lava flows. Extended work focuses on tephra and lava stratigraphy representing separate eruptions or pulses within a single eruption, relations of fissures and extension cracks to dike injection vs. crustal stresses, and the distinction between impact melts and breccias from volcanic equivalents.Our research will lead to the development of quantified models for autonomous feature recognition and navigation as well as assessment of target areas for resource exploration. Moreover, the characterization of how eruptive and emplacement mechanisms affect the morphology can improve the effectiveness of planetary surface evaluation and the interpretation of volcanic and impact history.

Author: MIKHAIL IVANOV

POSTER

Geology

Boguslawsky Crater: Analysis of a High-Latitude Impact Crater Sampling Pre-South Pole-Aitken Basin Crust as a Candidate Landing Site

Boguslawsky Crater (73oS, 43oE, ~100 km in diameter) is an ancient high southern latitude crater that is in the region that might contian polar volatiles. Neither Boguslawsky itself, however, nor its close surroundings show evidence for the suppression of the neutron flux from the surface. This means that in this region possible accumulation of hydrogen-bearing phases in upper regolith is below the level of detection by the LEND instrument, ~100 ppm, and analysis of volatiles in near-surface regolith is less likely. Boguslawsky is located within heavily cratered terrain that lies on a portion of the southern rim of the SPA basin. Thus, at Boguslawsky there is a possibility to analyze materials that compose the SPA rim and likely represent some of the oldest rocks on the Moon, which formed prior to the SPA impact event.We mapped the interor and floor of Boguslawsky, focusing in on two areas, 15 x 30 km each, at 72.9oS, 41.3oE (western landing ellipse) and at 73.9oS, 43.9oE (eastern landing ellipse) Three morphologically distinctive units are the most abundant within these areas: rolling plains (rp), flat plains (fp), and ejecta from crater Boguslawsky-D (ejf), which is on the eastern wall of Boguslawsky. The distinctly low depth/diameter ratio and interpretation of the possible structure of the crater interiors suggest that flat and rolling plains likely represent ejecta from remote and distant sources and have accumulated on the original floor of Boguslawsky since its formation. There is no positive evidence (dark halo craters, cryptomaria, mafic anomalies, etc.) for plains of volcanic origin modifying the crater floor. These materials are thus likely to be a combination of excavated pre-SPA crust and secondary ejecta material derived from distant craters. The nature of these units makes them desirable targets for potential sampling of ancient deep crust, contaminated to some degree by externally-derived ejecta.Ejecta from Boguslawsky-D comprises about 50% of the eastern ellipse and are among the stratigraphically youngest materials that were ejected from the Boguslawsky wall and re-deposited on the floor of the crater. The Boguslawsky wall cuts the ancient highlands that correspond to the southern portion of the SPA rim. Thus, ejecta from Boguslawsky-D likely consist of materials that form the SPA rim and, thus, represents a target of highest scientific priority on the Boguslawsky floor for sampling uncontaminated pre-SPA material.We have analyzed this region as a candidate landing site for future in situ and sample return missions. Neither the frequency distribution of slopes (30-m baseline), nor the rock (fragments larger than ~0.5 m) abundance on the surface of Boguslawsky-D ejecta, suggest that this unit is unsafe for landing.

Author: LAUREN JOZWIAK

Geology

ORAL

Lunar floor-fractured craters: constraining the timing of intrusion formation within the lunar volcanic history

Lunar floor-fractured craters (FFCs) are a class of 170 lunar craters characterized by shallow, fractured floors and associated morphologic features such as moats, mare and pyroclastic deposits. These craters are formed by stalling of a dike beneath the crater, and subsequent sill formation which uplifts and deforms the overlying crater floor. The geographic distribution of FFCs indicates that they preferentially form near the edges of lunar basins, although a subset of the FFC population is located in highland areas. The nature of FFC intrusions is an important factor to the understanding of the intrusive volcanic history of the Moon. Dating of these intrusions may offer additional insight into the chronology and associated mode (i.e. intrusive vs. extrusive) of lunar volcanism. We investigate the timing of FFC formation and examine whether or not this intrusive volcanic component formed in association with the main period of extrusive lunar volcanism, or if the intrusions span the entirety of lunar history with no spatial or temporal correlation to extrusive volcanic features. The stratigraphic ages of the FFC host craters span from the pre-Nectarian through the Eratosthenian, with a single example of a putative Copernican aged crater, Taruntius. The majority of the host craters are Nectarian to Imbrian in age. There are six FFCs whose interiors have been partially embayed by mare deposits following their intrusion events; these mare deposits are Imbrian in age. Host crater age places an older bound on the intrusion age for a given intrusive event, and the few examples of post-deformation mare embayment place a younger bound on intrusion age. Plotting the spatial distribution of the host crater ages reveals a link between ages of mare basalt deposits (via crater size-frequency distributions) and the host crater ages of regional FFC clusters. For example, there are several FFCs surrounding the Nectaris basin, all of which have a Nectarian host crater age. No stratigraphically younger craters around Nectaris have been deformed by the intrusive volcanic processes affecting FFCs; however, a paucity of younger craters adjacent to the basin edge means the intrusive activity cannot be constrained to the Nectarian. Indeed, the general lack of Nectarian-aged mare deposits combined with the Imbrian-aged crater degradation surface ages in Nectaris suggest that the FFC intrusions surrounding Nectaris formed during the Imbrian period. Many of the FFC host craters on the western edge of Oceanus Procellarum are Imbrian in age, as are the mare units located in that region. This correspondence between regional mare basalt ages and FFC host crater ages suggests that the intrusions which formed FFCs were emplaced during the main phase of extrusive volcanism on the Moon. Additionally, tectonic deformation associated with basin mare filling and loading shows close spatial correlation to FFC locations. Models of basin flexure have postulated that the extensional regime present in peripheral basin regions should be favorable to dike ascent, consistent with the suggestion that some FFCs are the surface manifestation of dikes propagated in response to basin filling and flexure.

Author: MARY KERRIGAN

Geology

ORAL

The West Clearwater Lake impact structure as a planetary analogue.

Impact cratering is the dominant geological process on the Moon, asteroids, and moons of Mars. The exploration and study of terrestrial craters is essential therefore to understand the origin and emplacement of impactites, the history of impact bombardment in the inner Solar System, the formation of complex impact craters, and the effects of shock on planetary materials. The West Clearwater Lake impact structure (WCIS) in northern Quebec, Canada (56°10 N, 74°20 W) is one of the field sites chosen by the FINESSE (Field Investigations to Enable Solar System Science and Exploration) team as an analogue to the SSERVI target bodies. We will present here an overview of the main scientific targets at this site, remote sensing analysis, and traverse planning for the first field expedition.WCIS is part of a rare example of a double impact structure, formed ~290 Mya, expressed as two adjacent circular lakes. WCIS is approximately 30 km in diameter and has an inner ring of islands (16 km diameter) representing the eroded remnants of the central uplift. Bathymetric data show that East Clearwater Lake (21 km diameter) also has a smaller, submerged, central uplift. The target lithologies for this impact crater include Precambrian granitic gneiss, granodiorite, and quartz monzodiorite of the Canadian Shield with cross cutting diabase dikes. Blocks of Ordovician limestone also occur in the melt rocks on the central islands.Fieldwork at WCIS will commence in August 2014 and will contribute to research areas including the modification of impact rocks and the structural mechanics of crater formation. Understanding the nature and emplacement history of impactites will involve the study of the impact melt rocks and breccias on the central island of WCIS, locating the contacts between melt-rich deposits, melt-poor lithic breccias, and target rocks. By examining their field relationships and sampling each of these lithologies we will be able to determine the local geologic setting. Another important research question addressed here relates to the effects of the volatile content of the target rock during the impact cratering process, and on the potential for an impact induced hydrothermal system. The energy released by a hypervelocity impact generates heat and mobilises volatiles and fluids in the near and subsurface. This activity creates environments that have been identified as hosting life in terrestrial craters and proposed as potential habitats for life on Mars and other planets. While secondary minerals have been identified at WCIS, no study has focused on the hydrothermal system of this crater. For questions relating to cratering mechanics we use remote sensing datasets as well as field techniques. Visible images at various spatial resolutions will provide important morphological and structural information that will be vital towards determining the various crater settings. This will be supplemented by DEMs and radar data to ascertain the structure and morphometric properties of the structure. In the field we will conduct lithological and structural mapping of the central islands within WCIS, which are interpreted as the central uplift.

Author: ALEXANDRA MATIELLA NOVAK
POSTER

Geology

Compositional Characterization of Lunar Impact Melt Flows Using Moon Mineralogy Mapper (M3)

Numerous impact melt flow deposits have been identified exterior to impact crater rims on the Moon [e.g., Hawke and Head, 1977; Denevi et al., 2012; Stopar et al., 2014; Neish et al. 2014]. We focus our attention upon examination of a portion of the 146 impact melt flows exterior to crater rim crests identified and described by Neish et al. [2014]. While many of these craters were initially discovered with optical imagery, Neish et al. [2014] identified many additional impact-melt flows using Mini-RF data. Numerous impact melt flows normally not visible to optical instrumentation are visible in S-band (12.6 cm) radar because their physical properties are distinct from their surroundings. Here, we further characterize these impact melt flows for their spatial emplacement, mineralogy, and chemistry using Moon Mineralogy Mapper (M3) data to place better constraints on aspects of impact crater processes. In particular, we aim to examine potential influences on impact melt emplacement including: mineral to glass proportions, the depth of excavation of target materials, and any evidence for remnant impactor materials or secondary recrystallization of these materials to different mineral assemblages relative to the surrounding target rock. M3 is useful towards this evaluation because it collected data in 85 spectral bands in the near-infrared ranging from 430 to 3000 nm at 140 to 280 m/pixel and achieved global coverage during the first half of 2009. Several types of near-infrared absorption analyses are appropriate for discriminating lunar deposits of various mineralogies and chemistries. Several initial lunar impact melt flow deposits have recently been examined using M3 data by Kramer et al. [2011], Dhingra et al. [2013], and Woehler et al. [2014]. For example, Dhingra et al. [2013] used a combination of the albedo at 1498 nm, the integrated band depth (IBD) at 2000 nm, and the band depth (BD) at 1900 nm to better characterize the spatial extent and composition of an impact melt flow deposit on the floor of Copernicus crater.Here, in order to further characterize the composition of this database of impact melt flows we utilize similar band and integrated band depth analyses to better discriminate their mineralogy, chemical composition, and the spatial extent of these melt deposits relative to monochromatic optical imagery and S-band data sets. The mineral and chemical composition of these melts will advance our understanding about the physical and chemical processes that aided in the emplacement of these flows subsequent to target impact.

Author: DANIEL MORIARTY

ORAL

Geology

The Diverse Local and Regional Stratigraphy of the South Pole – Aitken Basin

As the oldest and largest well-preserved basin on the Moon, the South Pole – Aitken Basin (SPA) is relevant to a broad range of lunar science topics including the composition, structure, and evolution of the lunar crust and upper mantle, the nearside-farside dichotomy, the absolute ages of lunar impact basins and the late heavy bombardment, and the mechanics of large impact processes. SPA is a high-priority target for future sample return missions, which could address each of these issues. Several focused efforts are underway in order to identify appropriate landing sites. We are currently working with Moon Mineralogy Mapper (M3) hyperspectral data in order to assess mineralogical diversity across the basin and evaluate the diverse local stratigraphy arising from both the SPA impact event and eons of subsequent cratering and space weathering processes. SPA exhibits a mafic-bearing composition with optical properties dominated by pyroxenes. Compositional variations among these pyroxenes are captured in the 1 _m and 2 _m spectral absorption bands as measured by M3. We have developed an approach to identify and characterize the compositions of the most pristine pyroxene-bearing exposures in the basin by measuring the depths and centers of these absorption bands in geologic context. The approach has been validated using a wide variety of laboratory spectroscopic data. Most of the well-defined mafic exposures in SPA are associated with crater structures of varying sizes. We use impact crater scaling laws (specifically regarding excavation, impact melting, and central peak formation) to estimate the origin depth of the exposed materials. By considering several exposures in and around several SPA craters, the local stratigraphy is evaluated. Due to the large size of SPA, the basin-wide stratigraphy can only be evaluated by integrating local geologic context including the regional history of impact cratering and magmatism. From an initial analysis of SPA subregions, several stratigraphic trends are beginning to emerge. Several (but not all) central peaks (which represent the deepest material exposed in a given crater) exhibit a narrow range in pyroxene composition relatively rich in Mg. Wall material (originating from shallower depths) is often of a different composition. The apparent uniformity of the central peak composition suggests the presence of a relatively homogenous Mg-rich zone tapped by these diverse craters. Material with distinctively more Fe- and Ca-rich pyroxenes occurs principally near the center of the basin (e.g., mafic mound). The observed relationships arise from some combination of SPA impact melt heterogeneity, diversity of crust/mantle clasts in basin floor materials, impact melt differentiation, redistribution of materials in subsequent impacts, mare basalt emplacements, and soil development. Analysis of the composition across additional local areas will further constrain the character and origin of the diverse stratigraphy observed in SPA.

Author: ZACHARY MORSE

POSTER

Geology

Analysis of Orientale Basin Ejecta and Evidence for Multistage Emplacement

Orientale Basin is a multi-ring impact structure centered at (266.5º E, -19.5º N) on the western edge of the nearside of the Moon. It is arguably the best-preserved multi-ring basin in the Solar System. The main crater rings (Inner Rook, Outer Rook, and Cordillera) extend approximately 300 km radially from the center of the basin, with ejecta extending an additional 800 km across the lunar surface. Our focus is on the Hevelius formation, or ejecta deposits of Orientale that extend out beyond the Cordillera Ring. Our goal is use new datasets available to achieve a better understanding of ejecta emplacement around multi-ring basins. High resolution, 100 m per pixel images from the Lunar Reconnaissance Orbiter's Wide Angle Camera were utilized to observe and map the Hevelius formation. Our initial analysis is thus far confined to the southwestern quadrant of the basin. Several areas of interest were identified which show noticeably different textures within deposits that lie conformably on the ballistically emplaced ejecta. Using data from the Lunar Orbiter Laser Altimeter, a 3D elevation model was generated to visualize the local topography. The LROC WAC images were then overlain on this 3D framework in order to identify any relationship between various morphologies and topography.Eight features have been identified that display distinct linear features consistent with the viscous fluid mass movement of molten rock. These features show movement down slope, following topographic lows around high elevation obstacles within their path. This morphology is consistent with the appearance and movement of flow structures within one radius of smaller craters. Furthermore, most of the identified structures display preferential orientation away from the center of the impact basin. These features are visibly distinct from the surrounding ballistic ejecta. It is clear that there are no nearby volcanic vents, eliminating the possible subsurface origin of these features. The shallow slopes over which these features extend also point to past molten flow as the source of their texture. Other mechanisms of large-scale material movement such as slumping or dry mass wasting could only be triggered on significantly steeper slopes. We suggest that these eight features are the solidified remains of impact melt flows that originated from the center of the basin. These deposits overlie ballistic ejecta in several locations which requires emplacement after the initial emplacement of the ballistic ejecta. This is consistent with the multi-stage ejecta emplacement model proposed by Osinski et al. (2011). Further mapping with LRO-WAC, NAC, and Mini RF will be undertaken for a more detailed analysis of the potential flow features.

Author: LILLIAN OSTRACH
ORAL

Geology

Detection of Non-Obvious Secondary Craters Through Measures of Crater Density

Interpretation of crater size-frequency distributions (SFDs) assumes that impact cratering is a random process and that the accumulation of craters over time on a surface reflects age. SFDs should only consider primary craters within a region assumed to consist of one geologic unit of uniform age [e.g.,1]; obvious secondary craters occurring in chains or clusters (including herringbone pattern ejecta) and the areas containing them must be excluded. However, recent investigations indicate that secondaries do not always display these typical features [2,3], suggesting that "non-obvious" secondaries dominate SFDs at diameters ≤1km [4]. Here we measured crater density in Mare Imbrium, revealing the presence of non-obvious secondary craters with diameters ranging from 500m to ~2km.Crater SFDs were measured on LROC WAC 100m/pixel mosaics for a region encompassing 2.27_10^5 km^2 within Mare Imbrium. The areal density of impact craters was determined from a point density calculation; output cell size and neighborhood radius were user-defined. Varying neighborhood radius alters the spatial structure observed in the density map. Although smaller neighborhood sizes emphasize statistical variability when considering regional density trends [i.e., too few samples per neighborhood for boundary identification; 5], their usage reveals clustering that may reflect non-obvious secondaries, which can then be verified through morphologic observations. In Mare Imbrium, the majority of grouped craters interpreted as non-obvious secondaries have diameters between 500m to ~850m, although craters as large as 2km were measured. Some crater groupings are within a higher albedo region (ejecta ray) than the surrounding terrain and can be traced back to a probable parent primary [i.e., Copernicus], lending support for a secondary origin. For other crater groupings, size-range distributions estimate the maximum secondary size at a given distance from a primary [6]; several parent craters likely contribute to the expansive rays and secondary crater chains observed, including Copernicus, Aristillus, Autolycus, Aristarchus, and in one case, Aristoteles. However, morphologic observations in LROC NAC images are required to determine whether the grouped craters have similar degradation states (same ages), because it is possible that the groupings are comprised of craters of different ages (non-obvious secondaries with younger primaries superposed). Nonetheless, measures of areal density aid in the identification and determination of non-obvious secondaries, and it is probable that at least some portion of the grouped non-overlapping craters represent far-flung, non-obvious secondaries, similar to those observed at Tycho [3] and Zunil [on Mars; 2].

Author: NOAH PETRO

ORAL

Geology

The Lunar Reconnaissance Orbiter – Highlights and Looking Forward

The Lunar Reconnaissance Orbiter (LRO) has been orbiting the Moon for five years. LRO science teams have delivered > 500 TB of data to the PDS, including higher-level data products (maps, mosaics, derived products), creating the largest single data archive for any NASA planetary science mission. Now, nearing completion of its first Extended Science Mission (ESM), LRO has proposed a second ESM (ESM2) in order to make new measurements in support of newly defined science questions. In addition to new science, LRO supports additional objectives that only LRO can currently provide, including the identification of safe landing sites for future landed missions, measurements that address Strategic Knowledge Gaps (SKGs), and can serve as a data relay for farside landers/rovers. In its current quasi-stable orbital configuration (polar orbit, ~30 x 180 km) LRO is capable of remaining in orbit for at least eight more years.LRO's seven instrument teams have been highly productive. Recent highlights include the identification of LRO-era impact craters, bi-static measurements of potential polar ice deposits, the variability of volatiles at and near the surface, and the variability of exospheric species. These recent discoveries form the core of LROs new objectives for the proposed ESM2. An overarching theme for ESM2 is change – on the surface, beneath the surface, and in the exosphere. The next two years of LRO operations will be an ambitious program of lunar and planetary science that are directly linked to the current Decadal Survey. Examples of the science LRO will address with 2 additional years of operations are given here. Evidence suggests that water molecules migrate across the lunar surface, LRO's ESM2 will characterize this water cycle on seasonal time scales with multiple instruments using innovative methods only recently validated. A surprising number of new impacts were recently detected. LRO will systematically survey these fresh impacts to determine their global abundance and the current flux of small meteorites while elucidating new information on impact dynamics. The thermal properties of the surface show unanticipated variability, particularly in the polar regions. We will employ new techniques to characterize the vertical as well as the horizontal structure of the regolith with never-before possible measurements. On the basis of innovative measurement approaches recently validated by LRO, a series of coordinated multi-sensor measurement campaigns will be used in ESM2 to address science questions associated with the Moon's interaction with the dynamic space environment.LRO continues to maximize its capabilities by operating in nadir and off-nadir modes. Off-nadir pointing has enabled new measurements by nearly all instruments and expands the range of science questions that LRO can address. For example, new off-nadir measurements by the LAMP instrument allow for a more detailed characterization of the exosphere. Also, off-nadir measurements by LROC, LAMP, and Diviner allow for broader phase angle coverage and thereby extends the photometric coverage of each instrument. These measurements are new to LRO and open up new avenues for understanding the Moon and airless bodies.

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ORAL

Geology

Sampling Impact Melt From the South Pole-Aitken Basin and SPA Pre-Nectarian Basins

The South Pole-Aitken Basin (SPA), possibly the oldest lunar basin, contains an array of basin, crater, and volcanic deposits. For many years, the nature of regolith components has been modeled in order to predict their origin, both vertically and horizontally, on the crust (local vs. foreign, lower crust/mantle vs. upper crust). These modeling efforts have concluded that the non-volcanic components of the regolith within SPA is dominantly locally derived, containing SPA derived impact melt with a small component of possible mantle derived materials (derived from two, large basins within SPA over very thin crust). Apollo and Luna regolith samples inform us that the regolith at any location of the Moon contain a diversity of materials, both in time and composition. As Bottke et al. present at this meeting PreNectarian (pN) basins may have formed in a narrow window of time following the formation of the Moon and SPA. Here we assess the likely contribution of pN basin ejecta to SPA regolith. We consider the contributions to the regolith of five pN basins identified by Fassett et al (2012; JGR), four interior to SPA (Amundsen-Ganswindt, Poincaré, Ingenii, Apollo) and the Australe basin located exterior to SPA.Following the approach described by Cohen and Cooker (2010; LPSC) we evaluate the fraction of melt from pN basins as part of ejecta deposits that are incorporated into the SPA regolith. First we consider the ejecta from Australe, a heavily degraded 880 km diameter basin. Impact melt from the formation of this basin may extend as deep as ~190 km (Cintala and Grieve, 1998) and may comprise ~8% of its ejecta. Given that Australe may be extremely old (see Bottke et al., this meeting), its ejecta may be extremely diluted within the SPA regolith, or absent entirely if the crustal properties at the time of formation are as unique as Bottke et al. describe. The other four pN basins are located inside or on the rim of SPA (listed above). These basins range in diameter from 315-480km in diameter with depths of melting likely from 60-100 km depth (assuming impact velocities of 15-20 km/s; Cintala and Grieve, 1998). As Petro and Jolliff described in 2012, both Apollo and Poincare have extremely thin crust in their interiors, implying that their melt could be derived from within the mantle. The fraction of melt in their ejecta deposits from each these basins is ~5%, not a large volume, but when the total contribution of basin ejecta to SPA is small (Petro and Pieters, 2008), their contribution to the regolith is not-insignificant. A well selected sample-return site within SPA would allow access to both SPA impact melt as well as material that can constrain the “SPA impact chronology” including SPA, and post-SPA basins. These in turn are ideal locales to test hypotheses of early impact fluxes.

Author: KENNETH RAMSLEY

POSTER

Geology

Impact ejecta from Mars to Phobos: Regolith bulk concentration and distribution, and the sufficiency of Mars ejecta to produce grooves as secondary impacts.

The surface of the martian moon Phobos is characterized by parallel and intersecting grooves that bear resemblance to secondary crater chains observed on planetary surfaces. Some researchers have hypothesized that Phobos grooves are produced by ejecta from martian primary crater impacts that intersects Phobos to produce parallel chains of secondary craters. To test this hypothesis we plot Keplerian trajectories of ejecta from Mars to Phobos. From these trajectories we: (1) set the fragment dispersion limits that are required to emplace the parallel grooves pits as observed in returned images from Phobos; (2) plot ejecta flight durations from Mars to Phobos; (3) map regions of exposure to secondary impacts and exposure shadows, and compare these to the observed grooves; (4) assess the viability of ejecta emplacing the large family of grooves covering most of the northern hemisphere of Phobos; and (5) plot the arrival of parallel lines of ejecta at oblique incident angles. We also assess the bulk volume of ejecta from large martian impact events and compute the total volume of Mars ejecta that intersects Phobos over geological time. On the basis of our analysis, we find that the predictions of this hypothesis (that Phobos grooves are produced by the intersection of ejecta from craters on Mars) are inconsistent with a wide range of Mars ejecta emplacement models and observations, and based on our analysis we conclude that the hypothesis is not valid. We also apply modeling methods that predict the flight of ejecta from Mars to Phobos to the question of the bulk concentration and distribution of Mars ejecta that is deposited in the regolith of Phobos. The gravity of Mars and the observation of a thick Phobos regolith suggests that nearly all ejecta from impacts on Phobos is inserted into temporary orbits around Mars and remains trapped in these orbits for several days to several hundred years until it re-impacts with Phobos to produce new generations of ejecta. Due to orbital mechanics, Phobos ejecta fragments typically re-impact on opposite hemispheres of Phobos from their previous impact sites, and when combined with the typical conical dispersion pattern of impact ejecta, this suggests that just two or three generations of re-impacts on Phobos are sufficient to uniformly disperse Mars ejecta fragments globally across the geographic surface of Phobos. For the present-day altitude of Phobos, we calculate a bulk concentration of Mars ejecta fragments in the regolith of Phobos of 250 ppm. Because Phobos has orbited at least 4,000 km farther from Mars during all but the most recent 500 Myr, this suggests that our prediction of 250 ppm for the bulk concentration of Mars ejecta will be found preferentially in the uppermost 0.5–1.0 meters of the Phobos regolith, and at depth, Mars ejecta fragments are likely to be found in bulk concentrations that are 10–60 x less than at the surface of Phobos.

Author: DEANNE ROGERS

Geology

POSTER

Using a volcanic analog site to understand causes of spectral and thermophysical variability over extraterrestrial volcanic terrains

It is well documented that individual lava flows of differing age can be distinguished in infrared spectral imagery due to variations in oxidation coatings, depositional silica, glassy rinds and spallation, and texture. Aside from spectral variability due to geochemical processes, however, there are other factors, such as volcaniclastic sediment cover, microscale surface texture (vesicularity), and macroscale surface texture (flow morphology), which affect the spectral and thermophysical variability observed from orbit. Here we build upon previous work by investigating infrared spectral signatures from surface units in and around the December 1974 flow in the SW rift zone. This area allows us to sample relatively fresh flows, older flows, ash deposits and fumarole mineralogies, all which are distinguishable in remotely sensed infrared data sets. Our objective is to understand the dominant factors which might contribute to observed spatial variations in spectral and thermophysical properties on other planetary bodies at both the sample and unit (remotely sensed) scale. Thermal Infrared Multispectral Scanner (TIMS) data (8-12 μm, 2 m/pixel) acquired over the December 1974 flow were processed and spectral units were identified. During a field campaign conducted in April 2013, multiple samples were collected from units of differing age, textures and spectral properties, and photographs and thermal images were used to document the surface textures and temperatures at a macroscale. A principal components transform was applied to the TIMS data. The first principal component, which accounts for ~82% of the total variance in the scene, is controlled by relative areal abundance of ash deposits, which exhibit relatively low ~11 μm emissivity, versus exposure of the pahoehoe subunit of the 1974 flow, which exhibits relatively low ~9 μm emissivity due to thin silica coatings. Nearly all of the spectral variability in the study region can be described as a mixture of these two components. The second principal component, accounting for ~14% of the total variance, is dominated by elevational differences, arising from imperfect atmospheric correction. The addition of temperature information allows for additional discrimination between spectrally similar units; for example, the 1974 a’a subunit is spectrally similar to relatively unmantled, older undivided flows. However, daytime temperatures between the two units differ by >4 K. Field-based thermal imaging shows that this temperature difference is likely due to increased area of shadowed surfaces associated with the clinker morphology of the a’a subunit. Thermal emission spectra acquired from samples of each unit show that, despite varying geochemical processes affecting the surface colors and microscale textures, most samples are spectrally similar to opaline silica. The silica spectral signatures do not appear to vary with coating color or age of the flow, with essentially identical signatures observed for white, grey, and blue coatings, as well as for older undivided flows. The most significant spectral differences are between unconsolidated ash samples and lava flows. These results suggest that both geochemical and physical properties strongly affect the remote sensing-based interpretations, and that spectral and temperature information should be used in tandem to guide field traverses.

Author: M. ELISE RUMPF

Geology

ORAL

Thicknesses of Lunar Lava Flows: Comparison of Layered Mare Units with Terrestrial Analogs

The Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) returns images with greater than 0.5 meter resolution, revealing layered deposits in the lunar maria. Many layers are interpreted to be sequences of basalt flows in the walls of impact craters and in pit craters, thought to be skylights above ancient lava tubes. Since the Apollo era, remote sensing and ground observations have estimated thicknesses of mare basalt flows to range from less than one meter up to 60 m or greater. Recently, thicknesses of individual layers measured using LROC NAC imagery of both pit craters and impact craters ranged from 2–14 m. Caution must be exercised in the interpretation of surface processes from morphologies of features that are close to the limits of resolvability because our knowledge of surface processes, including lava flow emplacement, on the Moon is not fully developed.We have conducted terrestrial analog studies to assess the accuracy of basalt flow thickness measurements in high-resolution lunar imagery. We mapped layered basalt flow sequences in valley walls in the Wai‘anae and Ko‘olau Ranges of O‘ahu, Hawai‘i, using WorldView-2 satellite images. Subsequent fieldwork allowed for validation of image interpretations through thickness measurements of in situ lava flows. Of the eight transects studied at three field locations, seven revealed WorldView-2 imagery average thickness estimates that were greater than average thicknesses measured in the field. Average image-derived to field-observed thickness ratios varied up to 6.3. A primary reason for this overestimation by remote sensing analysis is that many outcropping layers within a transect contain more than one individual flow, a distinction that is not visible in satellite imagery. The dense cores of ‘a‘_ flows are commonly resistant to erosion and provide protection for underlying layers, particularly more easily eroded pahoehoe flows or ‘a‘_ clinker, leading to single outcrops which contain several lava flow units.LRO NAC image measurements of layered mare basalts in the walls of impact craters provided flow thicknesses 2–5 times greater than those derived from images of the O‘ahu study sites. Lunar outcrops may contain more than one individual flow similarly to terrestrial outcrops, suggesting that estimates of lunar flow thicknesses are greater than actual flow thicknesses. Therefore, interpretations of lava flows in high-resolution lunar imagery may underestimate the number of flows present in a layered sequence and consequently overestimate the flow thickness. Current measurements of lava flow thicknesses derived from planetary images should be interpreted as maximum thicknesses. The accuracy of mare flow thickness measurements has broad implications for lunar exploration, for understanding of the thermal evolution of the Moon, and for the preservation potential of exogenous volatiles implanted in lunar paleoregoliths that were subsequently covered by active basalt flows.

Author: BHAIRAVI SHANKAR

Geology

ORAL

Exploring the North West Quadrant of the SPA basin

The South Pole-Aitken (SPA) basin is a top site for human and robotic lunar exploration as it can address questions including the solar system bombardment history, the effects of impact cratering, and the differentiation of planetary interiors. Several observations from orbit of diverse mineral assemblages derived from depth at SPA (including pure anorthosite, Mg-Spinel, and olivine-rich materials) has further fueled the interest to better SPA. Complex craters within SPA have the potential of sampling both crustal and mafic rich materials depending on their proximity to the basin interior. We look at several complex impact craters located along the north-west quadrant to address the potential sampling of SPA derived impact melt. A combination of spatial, spectral, and topographic datasets are used to assess the distribution of impactite materials of these craters. Birkeland crater, Eratosthenian aged, is 82 km in diameter with a well defined crater rim, terraced walls, and a flat crater floor. The central uplift is a consolidated peak with partial slumping along the north-east section. Previous studies have noted a strong thorium anomaly near Birkeland. O'Day crater, Copernican in age, is located north-west of Mare Ingenii and has a rim diameter of 71 km. The northern section of the crater floor is flat and filled with smooth materials. The southern section, in contrast, has a mixture of both smooth and rough deposits. The central uplift appears to be partially collapsed. The extent of impactite units are determined using optical data from the LRO NAC dataset. Impact melt deposits are identified primarily based on their visible characteristics (smooth surfaces, not associated with any volcanic source) using LRO-WAC global mosaics and individual NAC products. The crater floor at both craters is filled with large extents of smooth terrain, interpreted as impact melt rich deposits, and some hummocky terrain. Melts are observed along the terrace walls and overlying impact ejecta as pooled deposits within topographic lows. UV-VIS-NIR coverage from the Moon Mineralogy Mapper instrument is used to determine the compositional characteristics of the impactite units. Sampled spectral profiles indicate the presence of mostly noritic and gabbroic rock types at both craters with more mafic rich concentrations concentrated along the southern sections along both craters. The variable extent of mafic rich content within both Birkeland and O'Day allude to the variable stratigraphy in the target subsurface. The proximity of O'Day crater to Mare Ingenii may explain the concentration of mafic assemblages. Iron-poor compositions within the central uplifts at O'Day suggest the distribution of mafic rich materials is not completely continuous. The distribution of mafic rich units at Birkeland crater appear ambiguous. Proximity of these mafic rich areas to areas with thorium anomalies, and possible implications is currently being further investigated. Future work includes characterizing the texture and extent of impact melt deposits beyond the crater floor using Mini-RF data; and comparing the compositional observations to those within other areas of the SPA.

Author: ROBERT WAGNER
ORAL

Geology

Distribution, age, and formation mechanisms of lunar pits

Introduction: The Lunar Reconnaissance Orbiter Narrow Angle Camera (NAC) images the Moon with pixel scales of 0.5-2m. We systematically searched NAC images acquired with low incidence angles (0-50°) for vertical-walled collapse features using a semi-automated process. We located 231 pits, primarily in impact melts of Copernican craters [1].PitScan: We developed an algorithm (PitScan) to search for candidate pits. PitScan generally produces ~150 incorrect detections for each actual pit. In testing on images known to have pits, it missed 7% of mare pits and 40% of impact melt pits, the latter number likely due to the missed pits being below PitScan's minimum size cutoff.Pit discoveries: To date, we know of eight pits in mare basalt, two pits in highland terrain, and 221 pits in impact melt deposits of 29 craters. Three of the mare pits were previously known from the Kaguya mission [2]. The mare pits are spread across seven maria, and are mostly >40m across and >30m deep. The two highland pits occur north of Mare Serenitatis, and are 40-55m in diameter and ~25m deep. There is no compelling evidence for a tectonic origin for most mare and highland pits. A volcanic origin is possible for most of these pits, although only the Marius Hills pit is obviously related to volcanic processes.Impact melt pits are generally smaller than mare pits, with a median diameter of 16m and a median depth of 7m, and are frequently irregular in outline. Some much larger impact melt pits do occur, and are generally bowl-shaped, with diameters up to 900m and depths in excess of 100m. We interpret that void spaces in impact melt ponds likely formed as melt flowed after the surface solidified, perhaps due to isostatic adjustment of the ground beneath the melt pond and slumping of the crater walls.Age analysis: Neither the mare pits nor most of the impact melt pits are likely to have formed during the original emplacement of their host materials. From standard crater frequency distributions, craters near the mare pits should be in equilibrium at >200m [3], so small, crisp features such as these pits are very unlikely to have survived for >3 billion years. A similar argument holds for impact melt pits. King and Copernicus craters, with two of the highest pit concentrations, have melt pond crater equilibrium diameters of 30-50m [3,4]. Most of the pits on these melt sheets are <20m in diameter, indicating that they would likely have been destroyed had they formed at the same time as the melt pond. Most pits likely formed from recent impacts breaching thin sections in the roofs of pre-existing sub-surface voids.References: [1] Wagner, R.V. and Robinson, M.S. (2014) doi:10.1016/j.icarus.2014.04.002. [2] Haruyama, J. et al. (2010). 41st LPSC #1285. [3] Hiesinger, H. et al. (2012), doi:10.1029/ 2011JE003935. [4] Ashley, J.W. et al. (2012), doi:10.1029/2011JE003990.

Author: JENNIFER WHITTEN

ORAL

Geology

Lunar cryptomaria: The distribution and composition of ancient volcanic deposits on the Moon

The Moon has been affected by volcanism during the first half of its history. Most of these volcanic deposits are concentrated on the nearside and have crater retention ages that cluster around ~3.6 Ga. The age distribution of volcanic deposits suggests there was a sharp increase in the number of volcanic deposits beginning around 3.9 Ga, with few older deposits. Is this observation due to the lack of ancient volcanic deposits? Or is this gap between the formation of the anorthosite crust and the onset of observed mare volcanism due to limited preservation? In this study we strive to address this fundamental question and investigate what the distribution and mineralogy of ancient volcanic deposits reveal about the early thermal history and evolution of the Moon. Light plains are smooth high albedo surfaces that can be produced from basin impact ejecta ponding in topographic lows and by similar processes covering ancient mare deposits, creating cryptomaria. Cryptomaria are lunar volcanic deposits that have been covered with a layer of high albedo ejecta and have a similar morphology to impact-produced pre-mare Cayley Plains. In this study, we use a variety of remote data sets from the Lunar Reconnaissance Orbiter (e.g., Lunar Orbiter Laser Altimeter (LOLA), Diviner, Lunar Reconnaissance Orbiter Camera (LROC)) and Chandrayaan-1 (Moon Mineralogy Mapper (M3)) in order to assess the distribution and mineralogy of ancient cryptomaria as well as to identify criteria to distinguish cryptomaria from Cayley Plains produced solely by impact processes. M3 VNIR spectroscopic data were used to identify high concentrations of dark-halo craters (DHC) superposed on light plains. This type of occurrence of DHC, small impacts ~5-10 km in diameter that excavate low albedo material from beneath a high albedo surface, indicate the presence of a buried volcanic deposit beneath a high albedo surface. Mosaics of optical period 2c1 were produced with a resolution of 140 m/pixel. Approximately 30 different suspected regions across the Moon were analyzed for the presence of cryptomaria. From these 30 regions, only 18 were positively identified to contain cryptomaria on the basis of the presence of DHC. Once the cryptomare were mapped, other datasets such as topography, surface roughness, and rock abundance were used to characterize the surfaces of cryptomaria and the global distribution of Cayley Plains. M3 3x3 average spectra were collected from DHC and then processed using the Modified Gaussian Model to determine the pyroxene compositions of cryptomaria. Identified cryptomaria are concentrated around the nearside maria, especially in the eastern hemisphere. The most useful criterion for distinguishing between cryptomaria and end-member impact-produced Cayley Plains is a high concentration of DHC with a basaltic mineralogy. Analysis of the M3 spectra indicates that the mineralogy of all identified cryptomaria are consistent with mare basalts. These findings suggest that mare basalt volcanism was occurring prior to 3.9 Ga and that mantle dynamics and crustal thickness variations controlling the eruption of magmas onto the surface was in place during the emplacement of cryptomaria.

Author: SANDRA WISEMAN

POSTER

Geology

Aristarchus Olivine in Context With Circum-Imbrium Olivine-Bearing Deposits

The Aristarchus region contains geologically diverse deposits and the Aristarchus impact crater, located on the SE margin of the plateau near the contact between plateau materials and western Procellarum basalts, has exposed materials with diverse compositions. Of particular interest is the origin of olivine-bearing deposits that occur on the SE portion of the crater rim and ejecta. NW portions of the rim and ejecta expose plateau materials and are spectrally dominated by pyroxene in the VNIR. Spectra of the NW rim and ejecta are consistent with a noritic composition and with the inferred origin of the plateau as uplifted upper crust. Therefore, it is unlikely that the olivine- bearing materials, which exhibit a strong 1 micron olivine absorption and only minor pyroxene contributions in Chandrayaan-1 M3 spectra, are derived from plateau crustal materials similar to those exposed in the NW portion of the crater. Pyroclastic deposits on the plateau exhibit subtle glass features that are distinct from olivine. Plagioclase is exposed in the crater's central peak. Bright material in the crater's SW ejecta was inferred to be highly silicic in nature due to short CF positions identified in LRO Diviner data. Based on the geologic context, it is likely that the olivine-bearing ejecta is mixed with spectrally featureless plagioclase. Diviner data of the olivine-bearing material observed with M3 are consistent with a mixture of olivine and other shorter CF phases.The olivine-bearing deposits could be derived from a shallow pluton that is not represented by other surface exposures (perhaps related to the formation of the plateau and/or pyroclastic deposits) or re-excavated material originally deposited by the Imbrium forming event. As the olivine is associated with impact glass, melt and ejecta, impact processes may have played a role in its formation. Several olivine-bearing deposits have been detected in the vicinity of Imbrium. Such deposits may have been excavated from the lower crust or possibly upper mantle. There are several olivine bearing deposits in the vicinity of Imbrium. We investigated these deposits and looked for additional deposits using M3 data. Some of these deposits are spectrally dominated by olivine, although the spectra are not as spectrally pure as the Aristarchus olivine-bearing spectra. This may be because the deposits are smaller and thus more likely to be spatially mixed with other material. Given that spectrally similar deposits to those of the olivine-bearing Aristarchus ejecta are found in other exposures in the vicinity of Imbrium, the deposit in Aristarchus may represent re-exposed Imbrium ejecta.In order to differentiate between these hypotheses, we are integrating spectral data in the UV/VIS (LRO WAC), VIS/NIR (Chandrayaan-1 M3), and TIR (LRO Diviner) to further characterize the assemblages of minerals that occur in association with the olivine-bearing deposits in Aristarchus crater, western Procellarum.

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ORAL

Geology (Including Petrology)

mineral exploration on mars

On Earth there is an association between 50 to 300 km. diameter multi-ring impact craters and mineral deposits containing nickel, copper, gold, platinum, and uranium. The deposits tend to occur along the outer rings of the craters. Examples are the nickel-copper deposits at Sudbury, Canada and the uranium deposits in the Athabaska basin, Canada.Mineral exploration on Mars is proposed in the outer rings of multi-ring impact craters. The firsts stage in the detection of deposits would be ground geophysical surveys using magnetic, electromagnetic and radiometric detectors.

Author: DEREK SEARS

ORAL

Geology (Including Petrology)

Thermoluminescence Dating of Volcanism on Hawaii: Present Status and Future Prospects

Volcanism on the Big Island of Hawaii covers a timespan from the present to over a million years. Historic records and radiocarbon methods date the younger periods of activity, and K-Ar derived methods are especially effective for the older periods of activity. Between these limits, which includes much of the activity for Mauna Kea and Mauna Loa, thermoluminescence dating has often been proposed. Thermoluminescence, literally the light emitted when a sample is heated, records the number of electrons that have been excited to traps ~1 eV below the conduction band in a non-conducting crystal lattice, such as many silicates. The excitation is caused by the absorption of ionizing radiation and is therefore time-dependent. Thus the strength of the TL signal is proportional to absorbed dose. Since the dose-rate can be measured directly with dosimeters (such as those used in health physics) or estimated from the composition of the samples, it is possible to divide absorbed dose by dose rate to calculate age. Several authors have reported various degrees of success in applying this method. The major complication is the stability of the electrons trapped. Electrons released at low temperatures during heating are in shallow traps which may have been drained at ambient temperatures since eruption. However, methods have been found for identifying thermally stable traps – derived from TL pottery dating methods – and these are generally successful. More problematic is a form of instability displayed by volcanic lavas which is that they tend to "leak" electrons from the traps. The process is called "anomalous fading" and it is an instability that is difficult to correct for.I propose an alternative method of using TL to obtain ages for lavas in the 50,000-1,000,000 year range that is not subject to these complications. Instead of using the natural ("as is") TL signal, the sample has its natural TL removed (by heating to 500oC, for instance) and then exposed to ionizing radiation in the laboratory. The induced signal is a measure of the amount of crystalline phosphor (the mineral producing the TL, in this case feldspar). Literature data suggests that fresh lavas have a low induced TL (also referred to as "artificial TL", or, better, "TL sensitivity") and that the induced signal increases with time as feldspathic glass is converted to crystalline feldspar. With suitable laboratory calibration, I suggest that it should be possible to obtain a "crystallization age" that would reflect the time since the eruption of these lavas and cover a time-span not readily accessible by K-Ar and radiocarbon.We appreciate support for this work from NASA's SSERVI through the FINESSE (PI, Jennifer Heldmann) and RISE4E (PI, Timothy Glotch) teams.

Author: DAVID BAKER

POSTER

Geophysics

The Origin of Peak-Ring Basins on the Moon: Working Hypothesis and Path Forward in Using Observations to Constrain Models of Impact Basin Formation

Impact basins provide windows into the Moon's crustal structure and stratigraphy; however, interpreting the origin of impact basin materials requires constraints on the processes controlling basin formation and morphology. Peak-ring basins (exhibiting a rim crest and single interior ring of peaks) provide important insight into the basin-formation process, as they are transitional between complex craters with central peaks and multi-ring basins. New image and altimetry data from the Lunar Reconnaissance Orbiter as well as a suite of remote sensing datasets have permitted a reassessment of the origin of lunar peak-ring basins [e.g., 1-5]. We synthesize our morphometric, spectroscopic, and gravity observations of lunar peak-ring basins and describe a working hypothesis on the formation of peak rings that involves interactions between inward collapsing walls of the transient cavity and large uplifts of the crust and mantle that occur in the center of the basin. Our observations also demonstrate the importance of impact melting in modifying the interior morphology of large impact craters on the Moon. Major facets of our observations are then qualitatively compared and discussed in context of current numerical simulations of peak-ring basin formation in order to plot a course for future model refinement and development. We find that several major areas should be a focus for future numerical modeling of impact basins, including: 1) Central peak/Peak-ring dimensions: Systematic, quantitative comparisons between measurements of observed peak dimensions (e.g., height and diameter) and model predictions over the full sequence of peak morphologies are crucial. 2) Impact melt: Assessment of the post-impact modification of basin topography by impact melt (e.g., cooling and vertical contraction) may shed light on current inconsistencies between models and observations. 3) Peak-ring sampling depth and physical characteristics: More explicit predictions of sampling depth (or stratigraphic uplift) of central peaks and peak rings for a range of target and impactor conditions are needed, with more emphasis on non-terrestrial bodies. Important are estimates of peak-shock pressures and the physical characteristics of lithologies predicted to comprise the peak ring. 4) Faulting: Improved models incorporating the localization effects of faults on transient weakening and transient cavity collapse. Inclusion of discrete fault movements within the collapsing rim should improve the kinematic predictions of peak-ring formation. 5) Deep crustal and mantle structure: Reconciliation of current inconsistencies in observed crustal structure over peak-ring basins, as interpreted from GRAIL gravity data, and modeled crustal structure.

Author: WILLIAM BOTTKE

ORAL

Geophysics

Moon-Forming Impact Ejecta as the Source of the Earliest Lunar Bombardment

The earliest phase of lunar bombardment, defined by pre-Nectarian (pN) craters and basins on the Moon, has long been a mystery. Many argue pN impact events were derived from a long-lived leftover planetesimal population residing in the terrestrial planet region (Neukum and Ivavov 2001; Morbidelli et al. 2013). Problems with this model, however, have recently emerged. Analyses of ancient pN cratered terrains, as well as hydrocode models of South Pole Aitken (SPA) basin formation, suggest pN projectiles struck the Moon at ~ 10 km/s, 1.5-2 times lower than expectations from existing dynamical models of leftover planetesimals (Walsh et al. 2011; Marchi et al. 2012; Potter et al. 2013). Our own collisional and dynamical evolution simulations of leftover planetesimals have also had difficulty reproducing the characteristic signatures of pN craters/basins. Here we argue for an unexplored bombardment scenario that fits within the framework of planet and lunar formation models. We postulate that most pN impacts were produced by the relatively late return of ejecta from the giant impact (GI) that created the Moon. The GI was probably the biggest youngest impact to ever take place in the terrestrial planet region, and simulations indicate that several percent of an Earth mass was ejected out of cis-lunar space by this event (e.g., Jackson and Wyatt 2012; Canup 2012). Tracking this material using a suite of collisional and dynamical models, we find GI ejecta returns in some abundance to strike the Moon at ~10 km/s over an interval of many tens of Myr. En route to the Moon, the population undergoes extensive collisional evolution, enough to reproduce the wavy shape of the observed pN crater size frequency distributions upon impact. Our model results predict that the oldest pN- and SPA-cratered terrains formed ~8 and 15 Myr after the GI, respectively. SPA basin may have even formed earlier than these times, which would explain the absence of SPA-produced secondary craters on nearby pN terrains (Bottke et al. 2013). This would require processes on SPA to erase $20 < D < 100$ km craters for ~7 Myr after SPA formed, a plausible scenario considering the nature of the early lunar crust and lunar magma ocean (Elkins-Tanton et al. 2011). We also find that considerable GI ejecta hit the Moon prior to the oldest pN terrains, with the projectiles presumably slamming into a thin hot mushy lunar crust. The consequences of such impact events are unknown, but we suspect they would leave behind features similar to the flat palimpsest-like basins on Callisto. Such outcomes could explain why several prominent pN basins discussed by Wilhelms (1987), such as Procellarum, Australe, and Tranquillitatis, lack the topographic and gravity signatures of younger basins defined by GRAIL data. Accordingly, our results provide key constraints on the time-varying nature of the earliest lunar crust, the evolution of the lunar magma ocean, the size frequency distributions of both GI ejecta and leftover planetesimals, and planet formation itself.

Author: PETER CHI
POSTER

Geophysics

A Revisit to Magnetic Sounding of the Lunar Electrical Conductivity Profile with Apollo 15 Data

In the 1970s and 80s, studies using the Apollo surface and orbital magnetic field observations have estimated the size of the metallic core and the deep lunar electrical conductivity profile of the Moon. In these early magnetic sounding studies, the Apollo Lunar Surface Magnetometer (LSM) data were limited to those collected by the Apollo 12 mission. In recent years, the Apollo magnetic field data have been restored from their original, obsolete forms. The data restoration effort has made available the entire set of Apollo subsatellite magnetometer data and some of the Apollo 15 LSM data for scientific analysis. This study presents the transfer function analysis based mainly on the Apollo 15 magnetic field observations to infer the deep lunar electrical conductivity profile. The results are compared with those previously demonstrated by studies based on Apollo 12 and Explorer 35 observations.

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ORAL

Geophysics

Thermal Inertia of the Moon from Diviner Lunar Radiometer Measurements

Thermal inertia is a quantity that characterizes a material's resistance to changes in temperature. In remote sensing, thermal inertia is often used to infer physical properties of planetary surfaces by observing temperature oscillations occurring on known time scales. Unconsolidated particulate materials such as the lunar regolith tend to have low thermal inertia, and consolidated materials such as boulders and bedrock tend to have high thermal inertia. Long-period temperature oscillations (such as seasonal cycles) sense greater depths than short-period oscillations (such as a lunar eclipse); this allows retrieval of depth profiles of thermal inertia. Thus, it is possible to derive information about the history and present state of a geologic unit by measuring its temperature variations on various time scales. While the Moon's temperature has been measured for nearly a century, the Diviner Lunar Radiometer provides a dataset of unprecedented accuracy and coverage, as well as spatial and temporal resolution. We used Diviner data spanning nearly five years (60 lunar diurnal cycles) to constrain models of regolith thermal inertia, and mapped the results at a resolution of 128 pixels per degree from -70 to +70 degrees latitude. As we will show, the results clearly differentiate old and young craters by their relative thermal inertia values, and show regional and global patterns indicating the imprint of regolith formation by impacts over time. This new dataset has potential applications to a broad range of problems in lunar science, and the technique is widely applicable to airless bodies throughout the Solar System.

Author: PER J...GI
ORAL

Geophysics

A BALLISTIC MODEL FOR ANTIPODAL IMPACT MELT DEPOSITS ON THE MOON.

Data from infrared and visual LRO observations have revealed an anomalous area of ponded smooth deposits covering > 3000km2 at 41°N, 167°E (farside) of the Moon. This region of smooth deposits is the result of a momentary impact melt event around 100Ma and its origin is tied to the creation of the 85km diameter Tycho crater (43°S, 349°E). The location of the smooth deposits region is very close to the antipode of the Tycho crater. The antipodal field describes a topography of ponded basins (depth ≈5m) emplaced in what was then already extant crater arrays and indicates scenes of vigorous slushing and low viscosity flow patterns of impact melts commonly spilling into uphill gushes. The Tycho crater originated with an oblique angle (30° to 45°) impact of a huge bolide (≈10km) striking the Moon at typical solar system speeds (≈20km/s). The contact phase (≈1s) spouted high velocity jets at low angle and the following excavation phase (≈1minute) produced a spallation dust cloud and a fast expanding ejecta curtain shaped as a truncated inverted cone. Ejecta debris size categories and displacement distances adhere to the statistics of power law distributions such that a large fraction of ejecta material is found as sub-millimeter dust. 2-body ballistics for reconnection trajectories onto a spherical shaped Moon surface shows that antipodal path times are about 2 hours for an initial elevation angle of 25° (from the horizon), and that 45° is the upper limit for the elevation angle for any antipodal connection. Admitting the rotation of the Moon (≈27.3 Earth days) moves the location of Tycho's antipode to the observed center of impact melt region. Artemieva (2013) envisions the impact melt deposits as the result of ballistic antipodal flights of partially molten, man sized (≈1m) blobs bursting open on re-impact. This scenario requires a non-standard ejecta size distribution statistics and would necessitate a contemporary modification of the cratering scene which is not observed. We propose that the impact making the Tycho crater produced a vast and dense cloud of sub-millimeter sized particles where a sizeable fraction of these dust particles had a speed ≈ 2km/s and an initial ejection elevation angle ≈ 20°. The path refocusing aspect of the antipode flight admitted for an incessant embedding of these high speed dust particles into the regolith base during which the kinetic energy was dissipated into local heating through a frictional slow down against the burying soil (during the span of ≈ 1/2hour). Our one dimensional melt flow heat balance model incorporating radiation losses (temp4), heat loss to underlying soil, phase transformation (liquid-solid), and change of temperature of the embedding dust results in the onset of a lava flow down a 10° slope starting about 20 minutes after the re-impact event commences.

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ORAL

Geophysics

Theia's provenance: dynamical evolution of a late Impactor

In the Solar System's early history many processes have been proposed that depend on the dynamical state of the planets. Our study considers the possible dynamical states that produce a late Giant Impact (70 – 110 Myr) to form the Earth-Moon system. We investigate within the semimajor axis and eccentricity parameter space to determine the possible outcomes of a 5 terrestrial planet model of the Solar System for 3 different mass ratios (8:1, 4:1, and 1:1) of the Earth-Moon progenitors. Using angular momentum conservation, an initial condition is prescribed for the progenitor masses while using initial conditions for the other Solar System bodies from a well-known common epoch. Additionally we test the 4:1 mass ratio with a different giant planet configuration akin to the Nice model.We find local regions of our parameter space are more conducive to the outcome of a late Giant Impact. Mean motion resonances (MMRs) are identified between the terrestrial planets and used along with secular effects from the giant planets to indicate likely regions where a Giant Impact would occur. We characterize our results considering the estimated time of the Giant Impact, the resultant mass distribution of terrestrial planets, and the post collision mean angular momentum deficit (AMD). Case studies are presented illustrating the various possible outcomes with respect to their AMD relative to the current Solar System. Our statistical results show that a Nice model giant planet configuration can affect the occurrence of Giant Impacts and a restricted region of parameter space exists for all considered cases. The implications on planet formation scenarios and implicit habitability will also be discussed.

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ORAL

Geophysics

Lunar Atmosphere Probe Station: A Proof-of-Concept Instrument Package for Monitoring the Lunar Atmosphere

The lunar exosphere is the exemplar of a plasma near the surface of an airless body. Exposed to both the solar and interstellar radiation fields, the lunar exosphere is mostly ionized, and enduring questions regarding its properties include its density and vertical extent, the extent of contributions from volatile outgassing from the Moon, and its behavior over time, including response to the solar wind and modification by landers. Relative ionospheric measurements (riometry) are based on the simple physical principle that electromagnetic waves cannot propagate through a partially or fully ionized medium below the plasma frequency, and riometers have been deployed on the Earth in numerous remote and hostile environments. A multi-frequency riometer on the lunar surface would be able to monitor, in situ, the vertical extent of the lunar exosphere over time.We provide an update on a concept for a riometer implemented as a secondary science payload on future lunar landers, such as those recommended in the recent Planetary Sciences Decadal Survey report or commercial ventures. The instrument concept is simple, consisting of an antenna implemented as a metal deposited on polyimide film and receiver. We will present results from a performance test of the spectrometer and deployable antenna. The Lunar University Network for Astrophysical Research consortium is funded by the NASA Lunar Science Institute to investigate concepts for astrophysical observatories on the Moon.Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

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ORAL

Geophysics

Accretion of the Moon from disk produced by non-canonical impacts

The Earth's Moon is thought to have formed by accretion from a disk generated by a giant impact onto the Earth. In the canonical case, the impactor is a Mars-size object and the disk is composed primarily of impactor material (e.g. Canup 2004, 2008). Since the impactor likely had a composition different from that of the Earth, this seems at odds with the identical isotopic compositions of the Earth's mantle and the Moon. Pahlevan & Stevenson (2007) suggested that material exchange between the disk's and Earth's atmospheres could modify the composition of the disk to match that of the silicate Earth, resulting in compositional equilibration in O(100) years, a timescale much longer than that predicted for lunar accumulation from the disk (Ida et al. 1997, Kokubo et al. 2000).Using a more accurate modeling of the Moon's accretion from the protolunar disk, accounting in particular for the presence of vapor in the disk, we have shown that the Moon's accretion from the disk occurs on a timescale compatible with that required for equilibration to occur (Salmon & Canup 2012). However, it may be difficult for equilibration to occur without simultaneously depleting the disk of its mass (Melosh 2009). In addition, in our model a substantial portion of the Moon accumulates rapidly after the impact from material placed into distant orbits, and at least this portion appears unlikely to equilibrate with the Earth.Recently, new types of impacts have been proposed, involving either larger impactors (Canup 2012) or high-velocity impacts on a fast-spinning Earth (Cuk & Stewart 2012), and resulting in a protolunar disk whose composition is much closer to that of the post-impact Earth. These impacts, however, leave the Earth-Moon system with an excess of angular momentum. Subsequent capture of the Moon into the evection resonance has been argued to be capable of reducing the angular momentum of the Earth-Moon system by a factor of 2, making it compatible with its current value (Cuk and Stewart 2012).We have identified two main concerns with these non-canonical impacts: 1) they form more compact disks, with most of the mass located inside the Roche limit at 2.9 R_{Earth}. Incorporation of material from this inner region into the Moon is rather inefficient (Salmon and Canup 2012), so that formation of Moon-size objects may be compromised; 2) capture into the evection resonance seems possible only for a narrow range of orbital parameters. Previous work assumed that the Moon formed around 3.8 R_{Earth} (Cuk & Stewart 2012), while we found that the Moon forms in fact around 6 R_{Earth}.We have modeled the accretion of the Moon from non-canonical disks, and find that forming a Moon-size object requires very massive disks that may only be achievable by the impact-scenario of Canup (2012). We also find that the Moon is driven even farther away than in canonical cases, which may compromise subsequent capture into the evection resonance.

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ORAL

Geophysics

Are Density Variations on the Lunar Mantle Detectable with GRAIL Gravity Data?

When the lunar topographic contribution is removed from a lunar gravity model it provides a Bouguer disturbance that indicates mass excesses and deficiencies in the crust and possibly the upper mantle. Identifying gravity signals that originate at greater depth is a challenge. We try to determine if some of the larger lunar Bouguer disturbances are below the lunar crust and what affect that might have on the global Bouguer signal.

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ORAL

Geophysics

THE OXFORD SPACE ENVIRONMENT GONIOMETER

Measurements of the light scattering properties of the regolith of airless bodies in the Solar system, across wavelengths from the visible to the far infrared are essential to understanding their surface properties. This presentation will describe a new experimental setup, the Oxford Space Environment Goniometer (OSEG). The OSEG allows phase function measurements of samples to be made under vacuum (<10-4 mbar) whilst enclosed by a cooled (<150 K) radiation shield. The cooled radiation shield reduces the thermal background allowing phase measurements from the visible to the thermal infrared to be made. This work was originally motivated by the need for new emission phase function measurements to support analysis of data currently being returned by the Diviner Lunar Radiometer (Diviner) instrument. Diviner is a nine-channel mapping radiometer onboard NASA's Lunar Reconnaissance Orbiter. It has channels ranging from the visible to the far infrared (>400_m), with three mineralogy channels centered on the mid-infrared (8_m) [1].To fully interpret the brightness temperatures measured by a thermal infrared instrument requires a 3D thermophyscal model [e.g. 2,3]. However these models are dependent on knowledge of the phase function of scattered and emitted radiation across the visible, near and thermal infrared. These models typically assume that infrared radiation is scattered isotropically from the lunar surface. Although generally the models are in very good agreement with the measured brightness temperatures of the lunar surface, there are some discrepancies [2]. One possible reason for these discrepancies is that the scattering properties of the regolith in the thermal infrared are incorrectly estimated by the models. Although significant progress is being made in determining the scattering properties of the lunar soil in the visible and near infrared [e.g. 4,5], there is still limited or no data available on the scattering properties in the thermal infrared. Therefore, we are developing an automated, vacuum compatible goniometer (angular measuring device) system capable of measuring both the bidirectional distribution reflectance function and directional emissivity in the thermal infrared of samples under simulated lunar thermal conditions in the laboratory. The first use of the system will be to provide support for measurements made by the Diviner instrument in the thermal infrared. Some very initial measurements of the directional emissivity for a variety of different surface textures will be shown.
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Author: NATHAN WILLIAMS

Geophysics

ORAL

Fault Dislocation Modeling of Tectonic Landforms in Mare Frigoris

Previous work suggested that large-scale nearside basin-localized extensional tectonism on the Moon ended ~3.6 billion years ago and mare basin-related contractional deformation ended ~1.2 billion years ago [Lucchitta and Watkins, 1978; Solomon and Head, 1979, 1980; Hiesinger et al., 2003]. Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) [Robinson et al., 2010] high resolution (50-200 cm/pixel) images enable the detailed study of lunar tectonic landforms and further insight into the evolution of stresses. Populations of wrinkle ridges, lobate scarps, and graben are now observed at scales much smaller than previously recognized, and their morphology and stratigraphic relationships imply a complex deformational history [Watters et al., 2010, 2012]. Mare Frigoris (~45°N-60°N, 40°W-40°E) is one such area with abundant tectonic landforms now revealed by LROC [Williams et al., 2014].The most common tectonic landforms in mare basins are sinuous wrinkle ridges that have up to hundreds of meters of relief and are interpreted as folded basalt layers overlying thrust faults [Plescia and Golombek, 1986; Golombek et al., 1991; Schultz, 2000; Watters, 2004; Watters and Johnson, 2010]. They often consist of a narrow, asymmetric ridge atop a broad arch and sometimes occur radial to or concentric with the centers of some mare basins. Wrinkle ridges with these patterns have previously been associated with mascons – dense concentrations of mass identified by positive gravity anomalies. The thick basaltic lava thought responsible for lunar mascons causes flexure and subsidence to form wrinkle ridges [Solomon and Head, 1979, 1980]. However, Mare Frigoris is not associated with a mascon [Zuber et al., 2013], yet wrinkle ridges deform the mare basalts there [Whitford-Stark, 1990; Williams et al., 2014]. The origin of compressional stresses in non-mascon environments remains an outstanding question.A key step to better understanding the occurrence of wrinkle ridges in non-mascon basins is characterizing the behavior of the underlying faults. We expand upon methods used in Williams et al. [2013] and apply fault dislocation modeling to estimate geometries and displacements for selected wrinkle ridge faults in Mare Frigoris. Digital terrain models (DTMs) derived from LROC NAC stereo pairs [Tran et al., 2010] are used to constrain fault models. Using the system of analytical equations for deformation of a half-space defined by Okada [1985, 1992], we apply a genetic algorithm to invert ridge relief for fault parameters including dip angles, displacements, and depths of faulting along fault segments. Preliminary results for a portion of an S-shaped wrinkle ridge in western Mare Frigoris include maximum depths of faulting within the upper ~1-2 km, displacements of up to 200 m, and shallow (<40°) dip angles. These preliminary modeled values are comparable to estimates for other lunar and martian wrinkle ridges [e.g. Plescia and Golombek, 1986; Golombek et al., 1991; Schultz, 2000; Watters, 2004; Watters and Johnson, 2010], and suggest this faulting is likely confined to within the mare fill and not rooted deeply in anorthositic crust.

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ORAL

Geophysics

Global Surface Temperatures of the Moon

The Diviner Lunar Radiometer Experiment on NASA's Lunar Reconnaissance Orbiter (LRO) has been systematically mapping the global thermal state of the Moon since July of 2009. The instrument has acquired solar reflectance and mid-infrared radiance measurements in nine spectral channels spanning a wavelength range from 0.3 to 400 _m (Paige et al., 2010a). With nearly five years of data, the density of observations both spatially and in localtime is high enough that global diurnal temperatures can be adequately resolved to create global maps of surface temperatures. Nadir observations of radiance from the 7 infrared spectral channels are used to derive bolometric brightness temperatures, a measure of the spectrally integrated flux of infrared radiation emerging from the surface (Paige et al., 2010b). For the purposes of quantifying the overall heat balance of the surface and comparing with available models, the bolometric brightness temperature is the most fundamental and interpretable measurable quantity. With the diurnal temperatures determined for each 0.5 degree of binned data we create instantaneous global maps of surface temperatures for a given subsolar point.These systematic observations of the global thermal state of the Moon and its diurnal variability provides the ability to characterize the surface energy balance and develop an understanding of how the lunar regolith stores and exchanges heat. The highly insulating nature of the surface, the lack of an appreciable atmosphere to buffer surface temperatures, and slow rotation, result in an extremely complex thermal environment, especially when illumination angles are low such as in the vicinity of the dawn and dusk terminators and at high latitudes and the polar regions, where topography dominates the surface temperatures. Temperatures can vary by >100 K between shadowed and sunward facing slopes down to the smallest length scales resolved. In addition to topographic effects, daytime temperatures, which are in near-equilibrium with the solar flux, are influenced by radiative properties of the surface. Nighttime temperatures however are determined by the radiation of sensible heat stored in the subsurface during the day and therefore are sensitive to the thermophysical properties of the regolith (Bandfield et al., 2011, Vasavada et al., 2012).

Author: JAMES BURKE

POSTER

Human Exploration

HUMAN LUNAR SURFACE SCIENCE--PLANT GROWTH

Sustainable plant growth will be vital to lunar settlement, not only for human life support but also for many other uses. Much of the needed scientific and engineering knowledge is absent today. Earth-based and ISS demonstrations are essential. Robotic lunar surface experiments are the logical next step, but ultimately human-supervised, large-scale, long-duration proof tests must occur before any commitment to permanent dependence on lunar agriculture and forestry. Here we intend to describe and advocate small-scale activities that can begin now, as part of the GER roadmap's human lunar surface mission preparations, to advance world space development toward the goal of realistic reliance on plants grown on the Moon.

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ORAL

Human Exploration and Destination Drivers

The Near-Earth Object Human Space Flight Accessible Targets Study (NHATS)

The Near-Earth Object Human Space Flight Accessible Targets Study (NHATS) is an ongoing collaborative effort conducted by the NASA Goddard Space Flight Center (GSFC) and Jet Propulsion Laboratory (JPL). The objective of the NHATS system is to automatically monitor the near-Earth asteroid (NEA) population for round-trip mission accessibility in the context of potential future Human Space Flight (HSF) missions. The NHATS began in September 2010 under the auspices of NASA Headquarters Planetary Science Division of the Science Mission Directorate in cooperation with the Advanced Exploration Systems Division of the Human Exploration and Operations Mission Directorate. Automation of the NHATS system was completed on March 20, 2012 and the system has been operating continuously since then.Each day the automated NHATS system creates a list of NEAs newly added to the JPL Small-Body Database (SBDB) and NEAs with updated orbit solutions, and then applies the method of embedded trajectory grids to precise ephemerides for those NEAs, obtained via the JPL Horizons system. The results map out available round-trip mission opportunities to the NEAs between the years 2015 and 2040, with trajectory constraints enforced such that NEAs offering at least one round-trip mission solution meeting the constraints (e.g., total mission change-in-velocity less than 12 km/s, mission duration less than 450 days, and others) are more dynamically accessible than Mars. The daily results are automatically loaded into the NHATS web-site database and a summary email is transmitted to all NHATS mailing list subscribers. At present, 1180 of the currently known 10763 NEAs satisfy NHATS constraints and are, therefore, referred to as NHATS-compliant. The NHATS system also computes the next available optical and radar observation opportunities for all the NHATS-compliant NEAs as an aid to observers. NEAs are discovered almost daily, and often the time just after discovery is also the optimal time to provide follow-up observations to better estimate their orbits and characterize their physical nature. These follow-up observations are particularly important for those NEAs that could become potential future mission targets. Hence, it is prudent to monitor NEA discoveries daily and run an analysis to determine if any among them warrant additional study, as they might become attractive mission targets.In this talk we will provide an overview of the automated NHATS system and describe key characteristics of the NHATS-compliant segment of the NEA population, including orbital element distributions and relationships between accessibility metrics (e.g., change-in-velocity, mission duration) and NEA physical/orbital characteristics (e.g., absolute magnitude, synodic period). We will also show examples of NHATS-compliant NEAs for which follow-up observations were obtained after the NHATS system provided notification. Finally, we will place the round-trip HSF mission accessibility of the NHATS-compliant NEAs into context by comparing their accessibility to that of other destinations including lunar orbits, the lunar surface, Mars orbits, the martian moons Phobos and Deimos, and the martian surface.

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Human Exploration and Destination Drivers

ORAL

Geologist Crew Assignments During Delayed Communication Human Exploration of Solar System Surfaces

The 2011 Desert RATS field test simulated human scientific exploration of a Near Earth Asteroid. Test conditions involved 3 or 4 human crewmembers operating from prototype Space Exploration Vehicles (SEVs) and/or the Deep Space Habitat (DSH), command station, assumed to be in orbit around the target. Extra Vehicular Activities (EVAs) could begin from the DSH or the SEV. A 50-second one-way communication delay between the crew and Mission Control Center (MCC) and Science Support Room (SB) was introduced in this test. Internal Vehicular (IV) crewmembers were located inside the SEV, DSH or both, and experienced no time delay with EVA crew. The time delay made it impractical to carry on voice conversations with MCC and SB, and the crew adapted to depend on themselves for tactical science decisions. This situation placed increased responsibility on the crew geologists to perform the role of field science "PI". As a result, the position assignment of the crew geologists within the test produced intriguing results.In order to simulate microgravity, we tested two EVA modes of operation. One involved a theoretical self-contained propulsive backpack dubbed the "Super" SAFER (Simplified Aid For EVA Rescue). This capability enabled the crewmember to conduct an un-tethered EVA, but required anchoring to the surface and involved constraints on the number of allowable starts and stops to simulate propellant use. The second EVA mode involved the Astronaut Positioning System (APS), a simulated "robotic" arm that was attached to the fore of the SEV. The EVA crewmember controlled their position on the APS, while the SEV maintained position around the target. The APS constrained operational radius of the EVA crewmember, beyond which required a translation of the SEV.Prior to the test most participants expected that the best position for a geologist would be in an EVA role. However, test results showed that using a geologist in the IV position held distinct advantages. All crewmembers identified the IV position as extremely important during delayed communications operations. The IV role enabled a crewmember to access science files related to the tasks at hand, or past tasks, which were not available to EVA crewmembers. Furthermore, the IV crewmember had access to each EVA crewmembers data in real-time, enabling comparisons. Thus, assigning a geologist to the IV role enabled this crewmember to provide scientific situational awareness to the team on the surface when this input was lacking from the SB due to communication delay. Additionally, sample collection protocols are time-consuming. An IV geologist located in the SEV, in close proximity with the EVA crew, had the ability to plan subsequent science tasks while the EVA crew completed sample and site documentation. This essentially enabled "expertise multiplication" in much the same way that professional geologists work with field assistants. Because these results differ from our expected results we conclude that future exploration strategies that include an IV role require further field testing.

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Human Exploration and Destination Drivers

Irregular Mare Patches as Lunar Exploration Targets

Irregular Mare Patches as Lunar Exploration Targets. *S. E. Braden, M. S. Robinson, J. D. Stopar, S. J. Lawrence. (*sebraden@asu.edu) Irregular Mare Patches (IMPs) are small, morphologically distinct, basaltic features within the nearside lunar maria. More than 75 separate IMPs greater than 100 m in largest dimension are known [1-4]. Several IMPs have model ages of 18-58 Ma (from crater counting) [4], which is significantly later than the last phase of lunar mare basalt volcanism (1-1.2 Ga) [e.g. 5-7]. Morphologic and stratigraphic comparisons with other young lunar features provide an additional age constraint of <100-200 Ma [4]. The existence of young IMPs suggests long-lived nearside magmatism, which is a key constraint on lunar thermal evolution. Thermal models must provide enough interior energy to allow for low volume eruptions on the surface well into the Copernican period. As potential examples of some of the youngest volcanic material, IMPs are high priority targets for future lunar exploration.Confirmation of the young model ages through sample return would not only verify young basaltic volcanism on the lunar nearside but also provide new information on lunar magmatic evolution, while confirming methods for deriving estimated ages from crater counting on young surfaces, as well as adding to our knowledge of space weathering processes, regolith production, and the rate of erosive processes over relatively short lunar timescales (100 Ma). A large IMP would make a scientifically rewarding and exciting landing site for robotic or human exploration. For example, Ina (18.65°N, 5.30°E, 3 km) within Lacus Felicitatis, has high-resolution LROC Narrow Angle Camera [8] digital terrain models (~2 m/pixel), which enable detailed mission planning and hazard analysis, as previously demonstrated by [9, 10]. Images from the surface documenting any exposed outcrops and flow fronts will help to clarify the processes involved in the formation of IMPs. Additionally, IMPs are visually compelling exploration targets that showcase a unique and different view of the Moon, which has the potential to significantly engage the public. [1] Whitaker, E.A., 1972. NASA SP-289, p.25-84 to 25-85. [2] Schultz, P.H., 1976. Moon Morphology, 626 pp. [3] Stooke, P.J., 2012. LPS, 43, abstract 1011. [4] Braden, S.E., PhD Dissertation, Arizona State University, December, 2013. [5] Schultz, P.H., Spudis, P.D., 1983. Nature 302, 233-236. [6] Hiesinger H., et al., 2003. J. Geophys. Res. 108, 5065. [7] Hiesinger, H., et al., 2011. GSA Special Papers 477, 1-51. [8] Robinson, M.S., et al., 2010. Space Sci. Rev. 150, 81-124. [9] Braden, S.E., Robinson, M.S., 2011. GSA Special Papers 483, 507-518. [10] Lawrence et al. 2014 LPSC 45 2014 Abstract 2785.

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Human Exploration and Destination Drivers

New Analyses of the Moon's North Polar Illumination Conditions

We continue to enhance our LunarShader illumination simulation capability. This tool accurately determines the surface illumination conditions given a topography file and a selected date/time. Recent improvements includeWe have analyzed the Moon's north polar region using LunarShader and recent high-resolutions Digital Elevation Models. We have determined which sites receive the most illumination and then for those sites we fully characterize the illumination conditions. This analysis includes deriving several parameters of interest when planning either a lunar lander or rover mission. Examples of such parameters include:-1. Longest single period of continuous illumination2. Longest single period of constant shadow3. Mean amount of illumination4. Areas receiving no illumination (permanently shadowed)5. Earth-visibility mapsEach of these parameters is useful for different types of mission…1. Regions which have the longest single period of constant illumination, centered on mid-summer, are of interest for lander missions that want as long a duration as possible but are not designed to survive a lunar night. Analyses of the polar regions have revealed that locations exist that are continuously illuminated for several months.2. For extremely long surface missions, i.e. multiple years, a key parameter is the longest single period of constant shadow. This can determine the battery mass that is required to provide enough energy to heat key components. If the lander can survive the longest shadow it should be able to survive the whole year, so long as there is enough time to recharge once the longest shadow period ends before the next period begins.3. The mean amount of illumination simply shows the percentage of time that a point on the surface is illuminated. We have known for sometime that places exist that are illuminated for over 70% of the time during a winter day and 100% of a summer day. Often this type of study is undertaken to identify which locations to do detailed illumination studies on.4. Areas that receive no illumination, i.e. are permanently shadowed are known to be extremely cold and can harbor volatile deposits. Analysis of LOLA topography revealed that permanent shadow can exist at latitudes as low as 58°.5. LunarShader can also determine whether a location can see the Earth at a particular time. This is key information for either a lander or rover that will use Direct To Earth (DTE) communications rather than a relay communication satellite. sAdditionally we have developed to ability to determine when a lander is in line of sight of a deployed rover. This is useful for the mission scenario where the rover requires a lander for high data rate communications with Earth.

Author: JULIE CASTILLO-ROGEZ

Human Exploration and Destination Drivers

POSTER

Overview of a Preliminary Destination Mission Concept for a Human Orbital Mission to the Martian Moons

Introduction: The National Aeronautics and SpaceAdministration's Human Spaceflight ArchitectureTeam (HAT) has been developing a preliminary DestinationMission Concept (DMC) to assess how a humanorbital mission to one or both of the Martian moons,Phobos and Deimos, might be conducted as a followonto a human mission to a near-Earth asteroid (NEA)and as a possible preliminary step prior to a humanlanding on Mars. The HAT Mars-Phobos-Deimos(MPD) mission also permits the teleoperation of roboticsystems by the crew while in the Mars system. TheDMC development activity provides an initial effort toidentify the science and exploration objectives andinvestigate the capabilities and operations conceptsrequired for a human orbital mission to the Mars system.In addition, the MPD Team identified potentialsynergistic opportunities via prior exploration of otherdestinations currently under consideration. Activity Goal: The primary goal of the activitywas to determine whether an opposition-class mission(short-stay mission of ~30-90 days at Mars) providessufficient time to meet all or most of the science andexploration objectives at Phobos and Deimos, or if aconjunction-class mission (long-stay mission of ~450-540 days at Mars) is required. Study Areas: This presentation will provide a briefoverview of the HAT MPD activity, including discussionsof the following seven study areas that were investigated:1) science objectives and requirementsformulation; 2) exploration objectives and requirementsformulation; 3) destination activity implementationstrategy; 4) mission implementation strategy; 5)synergies with cis-lunar activities; 6) synergies withhuman and robotic precursor missions to NEAs; 7)robotic precursor requirements for a human mission toMars orbit and its moons. Activity Conclusions: Preliminary results fromthe MPD activity indicate that a meaningful humanorbital mission to explore both Martian moons androbotically retrieve a MSR cache from low Mars orbitcould be performed during an opposition-class missionopportunity. The initial destination mission plan indicatesthat 56 days are required to accomplish all scienceand exploration objectives. Margin and missionreduction opportunities provide confidence that a successfuland worthwhile mission could be completedwithin 60-90 days in the Mars system. Preliminaryparametric based estimates of the expected initial massin low-Earth orbit (IMLEO) for a transportation architectureutilizing nuclear thermal propulsion to supportan opposition-class mission (total duration of approximately550 days) range from 350 to over 1000 metrictons. The IMLEO is highly dependent on the Marsdeparture opportunity, with 2033 offering a minimumin the 2030-2040 timeframe. Detailed mass sizing andvolumetric analyses are needed to validate these initialestimates. Finally, the results from each of the activitystudy areas provide valuable information regarding thedevelopment of a human MPD mission and the synergisticactivities required prior to undertaking such anexploration endeavor.

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POSTER

Human Exploration and Destination Drivers

Analyzing the Genotoxicity of Lunar Dust

Rachel Caston and Bruce Demple, Department of Pharmacological Sciences, School of Medicine, Stony Brook University, Stony Brook, NY 11794If we hope to return humans to the Moon for long-term exploration and science, the effects of exposure to lunar dust need to be considered. Lunar dust may be able to cause DNA damage via the production of free radicals (see abstract by Schoonen et al.). Unrepaired DNA damage disrupts cell function and can lead to mutational changes after DNA replication. Mutations can lead to effects of varying severity, such as enabling cancerous growth or neurodegenerative disorders.To study the biological effects of the dust, the lunar soil simulant JSC-1A was used with a mouse neuronal cell line in culture. The cells were challenged in two ways. In the first set of experiments, JSC-1A was added directly to cells in culture dishes. In the second approach, JSC-1A dust was first washed with water for 5 hours, and cells were then challenged with either the washed dust or the wash water separately. In this way, mechanical and chemical interactions can be analyzed individually. Cell viability was analyzed using a dye-exclusion assay. In the preliminary experiments, the cells treated with either the prewashed dust or with the water used for washing had a greater survival than cells treated with the dust directly. This implies that both mechanical and chemical interactions affect the cells, or that unstable toxic products are eliminated by this simple treatment.The next step will be to perform similar experiments accompanied by an assessment of DNA damage. DNA damage will be measured using the "LORD-Q assay", which employs the polymerase chain reaction. The assay depends on the ability of a DNA polymerase to copy lesion-containing DNA, which is then amplified in successive rounds of the chain reaction. If the polymerase encounters a blocking lesion while replicating the DNA of the sample, a lower amount of PCR product is generated. In this way, DNA damage in control and JSC-1A treated cells will be compared.

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Human Exploration and Destination Drivers

Spacecraft-NEO water interaction during the Asteroid Redirect Mission (ARM)

In the asteroid redirect mission, a robotic spacecraft will collect a 5 to 7-m near-Earth object (small asteroid) and place it in orbit about the Moon. Subsequent manned sorties will then visit the asteroid in lunar orbit via the Orion spacecraft. However, any manned spacecraft will have its own water-rich exosphere, this water being outgassed from the spacecraft body and emitted directly via water dumps. This man-made exosphere will interact with the asteroid surface, possibly leading to the accumulation of contaminating water at cooler or shadowed locations on the body. In this presentation we consider the accumulation of spacecraft water emission at the asteroid. We will use the space shuttle water cloud examined in great detail in the mid-1980s as an analog. We will especially examine the water accumulation on the NEO as a function of assumed body temperature profiles. While a spacecraft-delivered contaminating water cloud might be considered a drawback, we suggest herein to use the water emission in a set of active experiments to gain new insight into the enigmatic water molecule-surface interactions that occur at the Moon and airless bodies. For example, past NLSI and SSERVI science studies suggests that defects can be sites for increased water adsorption. We thus suggest the astronauts can create a ‘defect garden’ that includes upturned asteroid soil, fractured soils (by astronaut impacts via hammer), and irradiated soils all designed to determine changes in in-situ surface water retention.

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ORAL

Human Exploration and Destination Drivers

FINESSE: Field Investigations to Enable Solar System Science and Exploration

The FINESSE (Field Investigations to Enable Solar System Science and Exploration) team is focused on a science and exploration field-based research program aimed at generating strategic knowledge in preparation for the human and robotic exploration of the Moon, near-Earth asteroids (NEAs) and Phobos & Deimos. We infuse our science program with leading edge exploration concepts since "science enables exploration and exploration enables science." The primary research objectives of our Science and Exploration programs are as follows: 1) FINESSE Science: Understand the effects of volcanism and impacts as dominant planetary processes on the Moon, NEAs, and Phobos & Deimos.2) FINESSE Exploration: Understand which exploration concepts of operations (ConOps) and capabilities enable and enhance scientific return.To accomplish these objectives, we conduct an integrated research program focused on scientifically-driven field exploration. Our research is accomplished through a sequenced field program at two strategically chosen field sites. Fieldwork will be conducted at Craters of the Moon National Monument and Preserve in Idaho and at the West Clearwater Lake Impact Structure in northern Canada. These sites have been chosen to address scientific questions pertaining to volcanism and impact science, respectively, as geologic analogs to the SSERVI Target Bodies. These terrestrial volcanic and impact records remain invaluable for our understanding of these processes throughout our Solar System, since these are our primary source of first hand knowledge on volcanic landform formation and modification as well as the three-dimensional structural and lithological character of impact craters. Impact cratering, for example, is the dominant geological process on the Moon, asteroids, and moons of Mars. Our scientific objectives are to understand the origin and emplacement of impactites, the history of impact bombardment in the inner Solar System, the formation of complex impact craters, and the effects of shock on planetary materials. Volcanism is another dominant geologic process that has significantly shaped the surface of planetary bodies. We will study the processes, geomorphic features and rock types related to fissure eruptions, volcanic constructs, lava tubes, flows and pyroclastic deposits. We will conduct scientific fieldwork under simulated lunar, NEA, and Phobos & Deimos mission constraints to evaluate strategically selected ConOps and capabilities regarding their anticipated value for future human-robotic scientific exploration. Throughout this field program, the assessment of our ConOps and capabilities will focus on understanding how and if each element of our research architecture leads to an acceptable level of science return. Our assessments will be systematically conducted at increasing levels of detail using a variety of quantitative and qualitative evaluation methods. FINESSE is composed of a world-class team of scientists, robotics and exploration subject experts, astronauts and operations specialists. We also infuse a variety of Education and Public Outreach (E/PO) activities into this unique project to bring the excitement of this science and exploration work to a broader community.

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Human Exploration and Destination Drivers

Water as a resource for science and exploration on the Moon

Water ice has been mapped in the polar regions of the Moon and appears to have a heterogeneous distribution. Remote sensing data at IR and FUV wavelengths are consistent with frost covering up to a few percent of the surface. Meanwhile, neutron and radar data that probe greater depths are consistent with localized areas with higher bulk concentrations of water. The distribution of water in lunar polar dregions is controlled by processes of scientific interest, including: impact gardening; thermal diffusion; sputtering; and photolysis. Any mission that can quantify the heterogeneity will provide important insights into the relative importance of these processes, and further will enable relating the current contents to the initial contents. Complementarily, knowledge of the distribution of water is important for In Situ Resource Utilization (ISRU) because the heterogeneity and abundance will drive the design of its harvesting. Furthermore, it may be advantageous to identify the locations of enriched pockets of water for exploitation.We present a summary of the present knowledge of the distribution of water ice in permanently shadowed regions. Next we model the effect of impact gardening on the distribution of ice in the coldest regions where thermal processes are not dominant. Comparing the model to data, we place an estimated age on the lunar volatile deposits in permanently shadowed regions. In addition, the model results are interpreted in terms of how the heterogeneity should be expected to affect ISRU on the Moon. We present the trade space between mobility and accessibility of volatiles in the coldest regions of the Moon.

Author: JOSE HURTADO

POSTER

Human Exploration and Destination Drivers

Geologic Activities During Microgravity EVAs: Lessons Learned from DRATS 2011 and RATS 2012

The 2011 Desert RATS and the 2012 RATS tests investigated exploration of a Near Earth Asteroid (NEA). We report lessons learned regarding geologic activities performed during analog microgravity extravehicular activities (EVAs). The 2011 test in the San Francisco Volcanic Field, AZ, examined field geology operations in two EVA modes using: 1) “Super” SAFER (Simplified Aid For EVA Rescue), a notional, self-contained propulsive backpack; and 2) Astronaut Positioning System (APS), a passive “robotic” arm attached to a Space Exploration Vehicle (SEV). SSAFER operations allow crewmembers to conduct un-tethered EVAs but require anchoring for geologic tasks. APS operations allow EVA crewmembers to control their position on the arm, with the SEV responsible for station-keeping and translation to reach areas outside the APS radius. The 2012 tests were conducted at the NASA Johnson Space Center and included mission simulations utilizing: a) a virtual reality (VR) system linked to an SEV flight simulator; and b) the Active Response Gravity Offload System (ARGOS). Using the former, pairs of crewmembers explored a VR model of asteroid Itokawa in two modes: 1) SSAFER EVAs with the piloted SEV supporting at a standoff distance; and 2) APS EVAs with the SEV maneuvering close to the target surface. ARGOS microgravity EVAs focused on sample collection and mobility tasks around analog target surfaces using a combination of tethers, APS, and various geologic tools. Results of the 2011-2012 activities led to the following conclusions. 1) High-fidelity science and engineering field-tests like DRATS 2011 require well-constrained assumptions about microgravity operations, e.g. time and resource (metabolic, propellant, etc.) expenditures required to complete EVA tasks. 2) Simulations like the 2012 RATS tests are important precursors to field tests to determine those constraints. Some issues, such as the need to account for propellant use and anchoring for SSAFER operations, were considered for the 2011 test but not quantified until the 2012 tests. Others became clear after the 2012 ARGOS work, including limitations imposed by microgravity on: translation across complex/hazardous terrain; use of tethers vs. APS & SEV vs. SSAFER for mobility/anchoring/station-keeping; manipulation of geologic tools and materials; and execution of geologic tasks. These will affect EVA timelines, influence traverse planning, and impact the design of equipment for field-tests and real missions. 3) Within the context of the microgravity environment and mission constraints, there are best practices for SSAFER- vs. APS-aided EVAs. Both the 2011 and 2012 experiences are critical for understanding the applicability of these operational modes. 4) High-fidelity VR simulations illustrate challenges that are not apparent in the field, e.g. the demands of piloting the SEV while simultaneously supporting the EVA crewmember. Similarly, although low-fidelity microgravity analogs, field-tests are crucial for investigating crew resource management and testing equipment and procedures in ways possible only in a high-fidelity science context. 5) Therefore, analog tests in support of human exploration of planetary bodies should include integrated field and laboratory (e.g. VR, ARGOS, Neutral Buoyancy Laboratory, etc.) simulations.

SSERVI-ESF14-135

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POSTER

Human Exploration and Destination Drivers

Astronaut Charging On an Asteroid

The plasma environment about a small near-Earth object is very complex, ranging from an electron-rich photoelectric sheath on the dayside to a very low density plasma wake region on the nightside. As a consequence, the surface potential can range from a few volts positive on the dayside to large negative values in shadowed regions. An astronaut as an isolated object in the solar wind plasma will also have his/her own electrical potential. Further, when electrically tethered to a larger spacecraft, the astronaut will be electrically connected to the ground of the spacecraft that likely floats to a positive potential (due to spacecraft photoelectron emission) relative to the plasma. The objective of this work is to consider the optimal location for an astronaut to make electrical 'first contact' with the asteroid, given the complex surface potential structure of the object from sunlight to shadowed locations. We consider cases where the astronaut is 1) isolated and immersed in the local plasma, 2) isolated and immersed in the local plasma but also developing a charge due to contact electrification, and 3) tethered back to the spacecraft and grounded to the potential of the spacecraft. In essence, we ask where is the safest place to make contact in order to minimize differential charging? We also consider the effect the spacecraft outgassing (and new ions) have on the environment and potential differences. We develop and present a set of recommendations on the remediation of the hazards associated with object-to-object electrical interactions.

Author: DAVID KRING

ORAL

Human Exploration and Destination Drivers

Implementing the GER: Human-assisted Lunar Sample Return from the Schrödinger and South Pole-Aitken Basins Using the Orion Spacecraft

The Global Exploration Roadmap (GER) outlines a series of lunar vicinity missions that include the Space Launch System (SLS) and the Orion spacecraft. Orion is being prepared for an Exploration Flight Test (EFT)-1 on a Delta IV in December 2014, followed by Exploration Mission One (EM-1) on the SLS in 2017, the latter of which is an un-crewed flight to a distant retrograde orbit around the Moon. EM-2 follows in 2021 with a crewed lunar orbit-capable system. With that orbital capability, astronauts could interact with a robotic asset on the lunar surface to facilitate sample return. Indeed, the GER anticipates human-assisted sample return within the decade and humans to the lunar surface are scheduled about four years later. A multi-year Global Lunar Landing Site Study to Provide the Scientific Context for Exploration of the Moon (Kring and Durda (eds.), 2012, LPI Contribution No. 1694) found that the Schrödinger and South Pole-Aitken basins are two high-priority targets. To adequately address both scientific and exploration objectives, sample return missions are required. The best results would be obtained by a trained crew on the lunar surface, but a productive iterative step would be to deploy a robotic asset to the lunar surface that is coordinated with an Orion flight. One of several potential landing sites within the Schrödinger basin would provide access to a pyroclastic deposit with ISRU potential and impact-generated lithologies that can help test the lunar cataclysm hypothesis and lunar magma ocean hypothesis.In a human-assisted sample return mission, astronauts on NASA's Orion vehicle and ESA's service module could be sent to an orbit around the Earth-Moon L2 point ~60,000 km above the lunar far side surface or to a distant retrograde orbit (DRO) that also passes over the far side surface. Currently, the target DRO passes ~70,000 km above the lunar far side. In parallel, a robotic asset could land within the Schrödinger and/or South Pole-Aitken basins and collect samples for return to Earth. A lander and rover could maintain contact with Earth through Orion. Moreover, astronauts on Orion could teleoperate the rover to reduce mission risk, enhance scientific return, and test operational concepts for future missions, including those needed to execute a Mars exploration program. An ascent vehicle on the robotic asset could return samples to the Orion vehicle for return to Earth or, with the addition of a capsule, directly to Earth. Our studies of mission operation time lines indicate Orion would have 20 and 10 days of communication with the surface asset from an L2 orbit or DRO orbit, respectively, while accommodating ascent vehicle rendezvous for sample transfer to Orion with a total mission duration of about a month.

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Human Exploration and Destination Drivers

High-Priority Destinations for Lunar Exploration

A systematic program of human and robotic lunar exploration will greatly advance all planetary science and exploration objectives [1]. Precursor campaigns should include rovers, sample return, and ISRU demonstrations preparing for human missions[2]. LRO produces data essential for scientific exploration [3-6] and informing mission design [7-9]. Site assessment is critical to determine optimal precursor mission strategies, particularly sample returns. Sample return addresses : 1) Magmatic evolution of the Moon, 2) volcanic processes, 3) time-stratigraphic relationships, and 4)resource potential. Interior Evolution: Sample return of materials from Hansteen Alpha, Lassell Massif, Gruthuisen Domes, and/or Mairan T enables understanding the composition and emplacement style of these silicic volcanic constructs [10-14].Volcanic Processes: Sample return from low mare shields could determine compositional or other differences between low shields and plains-type mare basalts [15-17]. Candidates include Marius Hills, Hortensius Domes, and the Isis/Osiris cones. Time-Stratigraphy: Establishing precise ages for recent lunar geologic events calibrates cratering statistics that are applied to other terrestrial planets [e.g., 18,19]. The youngest (~1 Ga) Procellarum basalts [20] and Copernicus crater are ideal locations to age-date geologically recent events.Resource Potential: Regional pyroclastic deposits Aristarchus and Sulpicius Gallus are excellent locations to assess the properties and compositions of these resources [21,22]. Pyroclastic samples would enable qualification of ISRU hardware, expanding the capability and reducing the costs of Solar System exploration. References: [1] NRC (2007) SCEM Report [2] Lunar Exploration Roadmap [3] Robinson M. et al. (2011) LPI 1646, 72 [4] S. Lawrence et al. (2010) LPI 1595, Abs. 35. [5] J. Gruener et al. (2009 AGU 31, 0010. [6] M. S. Robinson et al. (2010) SSR 150, 1–4, pp. 81–124. [7] E. J. Speyerer and M. S. Robinson (2013) Icarus, 222, 1, pp. 122–136. [8] J. E. Gruener and B. K. Joosten (2009) LPI 1483 pp. 50–51. [9] E. J. Speyerer et al. (2013) LPSC 44, 1745. [10] T. D. Glotch et al. (2010) Science, 329, 5998, pp. 1510–1513. [11] B. T. Greenhagen et al. (2010) Science, 329, 5998, pp. 1507–1509. [12] B. L. Jolliff et al. (2011) Nat. Geosci, 4, 8, pp. 566–571. [13] B. R. Hawke et al. (2003) JGR 108, p. 8.[14] J. W. Ashley et al. (2013), LPSC 44, Abstract 2504. [15] S. J. Lawrence et al. (2013) JGR, doi:10.1002/jgre.20060. [16] J. B. Plescia, (2013) 2013 NASA Lunar Science Forum. [17] P. D. Spudis et al. (2013) JGR, doi:10.1002/jgre.20059 [18] H. Hiesinger et al. (2011) GSASP 477, pp. 1–51. [19] D. Stöffler and G. Ryder (2001) SSR 96, pp. 9–54. [20] S. J. Lawrence et al. (2011) LPI 1611, 5047. [21] B. R. Hawke et al. (1990) Proc LPSC 20 pp. 249–258. [22] B. R. Hawke et al. (1991) Proc. LPSC 21 pp. 377–389.

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Human Exploration and Destination Drivers

Managing, mitigating and adapting to the impact of communication latencies on human-robotic scientific exploration – lessons from Pavilion Lake Research Project field deployments.

Regardless of when humans ultimately venture beyond Low Earth Orbit, and regardless of where we explore, there will be certain operational, technical and scientific parameters that will cross-cut the exploration architecture. Communications, and specifically the design principles and operational methodologies required to manage unavoidable time-delayed communications during human scientific exploration, will be critical to our future successes in human space flight as we explore at increasing distances from earth. Given that science will undoubtedly be a key driver in future human exploration of the Moon, NEAs and beyond, the effects of time-delayed communications on science, science operations and productivity, mission operations and technological management require focused examination as these effects are not yet understood. Here we present results and lessons learnt from a real (non-simulated) field science program within which simulated time-delayed communications experiments were performed to assess the impact of these latencies on scientifically driven exploration. This research was aimed at measuring the impact of lunar-like, and NEA communications delays on both scientific productivity and human factors, such as workload, during our real science operations. We also examined the capabilities, operations concepts and communications protocols required to manage tethered Science Divers, Surface Support Crews, and a distributed Science Backroom Team. Our research was conducted during the 2011 and 2014 Pavilion Lake Research Project (PLRP) field deployments to Kelly and Pavilion lakes in British Columbia, Canada. The field activities involved a mix of DeepWorker submersibles, SCUBA divers, and Remotely Operated Vehicles (ROVs), which were used to study microbialite morphogenesis in Pavilion and Kelly lakes, and the potential for biosignature preservation in these carbonate rocks. Further background on the field deployment activities will also be presented.

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Human Exploration and Destination Drivers

Developing the "Lunar Vicinity" Scenario of the Global Exploration Roadmap

The Global Exploration Roadmap (GER, [1]) has been developed by the International Space Exploration Coordination Group (ISECG – comprised of 14 space agencies) to define various pathways to get humans beyond low Earth orbit and eventually to Mars. Such pathways include visiting asteroids or the Moon before going on to Mars. This document has been written at a very high level and many details are still to be determined.In this presentation, we develop the GER "Lunar Vicinity" scenario by mapping a number of relevant reports/documents into the GER. These are in no way meant to encompass everything that is relevant to this process (others should be added – e.g., the soon to be published JAXA Space Exploration Roadmap). This exercise is intended to demonstrate that existing documents can be mapped into the GER despite the major differences in granularity, and that this mapping is a way to promote broader national and international buy-in to the GER.The Global Exploration Roadmap: The common goals are as follows: •Develop Exploration Technologies & Capabilities.•Engage the Public in Exploration.•Enhance Earth Safety. •Extend Human Presence.•Perform Science to Enable Human Exploration.•Perform Space, Earth, and Applied Science.•Search for Life.•Stimulate Economic Expansion.With Mars being the goal there are three paths articulated - Exploration of a Near-Earth asteroid; Extended Duration Crew Missions; and Humans to the Lunar Surface. The GER gives 5 goals for the Lunar Surface scenario:•Technology test bed (surface power systems, long distance mobility concepts, human-robotic partnerships, precision landing).•Characterizing human health and performance outside Earth's magnetosphere and in a reduced gravity environment.•Conducting high priority science benefiting from human presence, including human-assisted lunar sample return. •Advance knowledge base related to use of lunar resources.•Explore landing sites of interest for extended durations.The Mapping Process: documents highlighted here are as references [2-9]. Other documents will be added to this list prior to the presentation.References: [1] Global Exploration Roadmap (2013) http://www.globalspaceexploration.org, [2] Ehrenfreund et al. (2012) ASR 49, 2-48. [3] SKGs for the "Moon First" Human Exploration Scenario (2012) http://www.lpi.usra.edu/leag/GAP_SAT_03_09_12.pdf [4] LER (2013) http://www.lpi.usra.edu/leag/ler_draft.shtml [5] NRC (2007) http://www.nap.edu/catalog/11954.html [6] Crawford et al. (2012) Planet. Space Sci. 74, 3-14. [7] Crawford (2010) Astrobiology 10, 577-587. [8] Lunar Science Workshop (2007) NASA Advisory Council Wksp Science Associated with the Lunar Exploration Architecture. http://www.lpi.usra.edu/ meetings/LEA/finalReport.pdf [9] NASA's Strategic Direction (2012) http://www.nap.edu/catalog.php?record_id=18248

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Human Exploration and Destination Drivers

Using the Moon to go to Mars: Why Lunar Exploration Should Not be Ignored

The Lunar Exploration Analysis Group (LEAG) was tasked by the NASA Advisory Council in 2007 to developed a comprehensive Lunar Exploration Roadmap (LER; [1]) as part of the Vision for Space Exploration. The LER is comprised of three themes: Science, Feed Forward, and Sustainability. It is the Feed Forward theme that is the subject of this presentation.The purpose of the Feed Forward theme is to establish mission risk reduction technologies, systems, and operational techniques that could be developed through a lunar exploration program using 2 criteria: Mars/Small Body Risk Reduction Value: How well do the candidates address the key risk reduction areas identified through NASA's robotic and human Mars/Small Body mission planning studies; and, Lunar Platform Value: Do candidates leverage the unique attributes of a lunar program to achieve success – or – would other platforms be more effective from a technical/cost perspective. There are two goals under this theme that are focused on Mars (with the third focused on asteroids): Goal FF-A addresses hardware (Identify and test technologies on the Moon to enable robotic and human solar system science and exploration); Goal FF-B addresses operations (Use the Moon as a test-bed for missions operations and exploration techniques to reduce the risks and increase the productivity of future missions to Mars and beyond).The LER presents a foundation upon which to develop a long-term plan that will enable humans to explore Mars. The Moon's vicinity and environment make it the logical place to retire risk through the development of systems and operations for human activities off planet. Having the Moon in the critical path to Mars has a number of important and critical advantages that are focused on the low gravity lunar environment, as well as the Moon's close proximity to Earth:•Testing bioregenerative technologies that are needed to support wastewater processing, air revitalization and food production.•Perform long-duration testing of an integrated surface life support system that is needed to simulate Mars surface stay times exceeding 500 days.•Testing countermeasure technologies that need to be tested so as to assure human performance remains at an acceptable standard.•Testing surface mobility systems (range, duration, terrain, time).•Testing surface fission power system technologies that should be capable of being autonomously deployed and able to initiate/sustain power generation without human interaction.•Testing monolithic habitat technologies on the lunar surface that incorporate the capability for autonomous deployment and operations without human intervention.•Testing radiation shielding technologies outside of the Earth's magnetosphere.•Testing dust mitigation technologies to prevent dust from interfering with mechanical systems and causing health problems for astronaut crews.•Testing forward and backward planetary protection technologies to prepare for human and robotic operations on Mars.•Conduct a Mars surface mission simulation on the Moon.•Develop cost effective surface systems that can be developed in a relatively short period of time.[1] Lunar Exploration Roadmap (2013) http:// www.lpi.usra.edu/leag/ler_draft.shtml

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Human Exploration and Destination Drivers

Characterization of Smooth Deposits Within South-Pole Aitken Basin: The Search for Impact Melt Deposits

Recent lunar missions, including the Lunar Reconnaissance Orbiter (LRO), Chandryaan-1, Kaguya/SELENE, and the Gravity Recovery and Interior Laboratory (GRAIL), enable researchers to answer outstanding questions critical to lunar science in preparation for future robotic and human exploration. The South Pole-Aitken basin (SPA) is identified as one of the highest-priority targets for future exploration and sample return because multiple science objectives can be addressed, including investigations related to the bombardment history of the Solar System, the lunar interior (including crustal structure and mantle composition), and the volcanic evolution of the Moon [1,2]. Impact melts form during the impact process; radiometric ages for melts therefore date an impact event. Although SPA is heavily modified by subsequent basin, crater, and mare materials, by identifying the oldest surfaces from remote sensing data, it may be possible date the SPA event (and those impact basins located within SPA) via a future sample return mission (e.g., MoonRise). Previous investigations employed multiple techniques and datasets [e.g.,3-6], and we build upon these findings to further characterize geology within SPA. Our efforts place particular emphasis on smooth deposits interpreted to be impact melt or basin ejecta interior to and surrounding "young" impact craters (e.g., Alder, Bhabha, Bose, Finsen), although we do include mare and cryptomare deposits in our survey. Our primary objectives are to (1) determine smooth deposit origin on the basis of albedo, composition, embayment relations, and stratigraphic relations to crater ejecta, (2) determine the relative ages of both the smooth deposit and its associated crater, placing the unit into stratigraphic context with other SPA basin materials, and (3) identify locations hosting the oldest surfaces (presumed to be SPA-derived impact melt) in SPA. In a comprehensive mapping effort to better understand the geology of the SPA basin using new remote sensing data, we utilize multiple datasets (e.g., LRO, M3) at high resolution to characterize geologic units on the basis on morphology (e.g, degradation state, stratigraphic relations), composition, and in some cases, crater densities [7]. [1]Committee on the Scientific Context for Exploration of the Moon National Research Council (2007), "The Scientific Context for Exploration of the Moon: Final Report", National Academies Press.[2]Committee on the Planetary Science Decadal Survey (2011) "Vision and Voyages for Planetary Science in the Decade 2013-2022", National Academies Press.[3]Wilhelms, D. (1987) The Geologic History of the Moon, USGS Prof. Pap. 1348.[4]Pieters, C.M. et al. (2001) JGR 106, 28001-28022.[5]Petro, N.E., Pieters, C.M. (2004) JGR 109, E06004.[6]Moriarty et al. (2013) JGR Planets 118, 2310-2322.[7]Kirchoff, M.R. et al. (2013) Icarus 225, 325-341.

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Human Exploration and Destination Drivers

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Planetary Protection For Future Human Missions -- Addressing Science Gaps And Providing Input For Future Systems, Operations And Equipment For Mars

COSPAR planetary protection (PP) principles and implementation guidelines for human Mars missions require protection of Mars from forward contamination during operations and exploration, protection of astronaut health and safety throughout the long duration mission, and safeguarding of Earth from back contamination upon return. Engineers and scientists have begun to analyze how these requirements will constrain the diverse systems, operations and equipment necessary for future missions While experiences from ISS and other activities in Earth orbit provide a strong foundation for planning human missions back to planetary surfaces (the first time since the Apollo program), planetary protection requirements for introduce an assortment of new challenges and data gaps, particularly due to recent new understanding about microbial life and environmental conditions on potentially habitable solar system bodies, like Mars. A number of recent NASA and international workshops and studies have identified particular concerns associated with planetary protection needs, including information associated with human health and life sup-port requirements; EVA, surface operations, contami-nation mitigation methods; plans for in situ resource utilization (ISRU); equipment and procedures for science exploration, sample collection and handling; and quarantine methods, containment, and systems intended to avoid back contamination of Earth. In some cases, these concerns overlap with areas of active science investigations. It is clear that additional science research will be essential for narrowing knowledge gaps and contributing to productive human missions that maximize science return. Important information can be collected during robotic precursor missions, in labs or analogue sites on Earth, and through research and experiments on ISS. Presumably less restricted missions to asteroids can also be used for gathering data or testing feed-forward concepts associated with planetary protection. This presentation summarizes recent information under discussion by NASA and international groups about science and technology needs for meeting PP constraints on future human missions, particularly to Mars. Precursor science data will be important not only preliminary mission planning, but also as input for the upcoming NASA process for drafting a Planetary Protection Procedural Instruction (NPI) for Hu-man Extraterrestrial Missions . Among the key science research areas identified are those that increase information on survival of spacecraft and human associated terrestrial organisms and their molecular components in ambient martian environments; information on sterilization and monitoring capabilities for wastes material and mission-associated equipment and samples; information on distribution of water on Mars, at both the macro- and micro-scales, both near-surface and deeper; and information on near- and far-field contamination transport. Filling strategic science gaps with focused investigations will be important for eventual mission designs and operations, particularly those that control, mitigate or eliminate risks associated with biological contamination.

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Human Exploration and Destination Drivers

Lunar Environmental Management: What's Needed to Guide Future

With increased interest in exploration and use of outer space beyond LEO, it is clear that the international community will soon need to address questions about the future activities of multiple stakeholders on the surfaces of the Moon and other celestial bodies and the potential conflicts of uses that may arise—some of which are very different than experiences on Earth and in Earth orbit. Under the Outer Space Treaty, there are clear policies and regulations regarding planetary protection during exploration, but currently no standardized guidelines for environmental management, stewardship or responsible use on planetary surfaces. While recent NASA guidelines to preserve the Apollo landing sites are an example of an incremental approach to addressing concerns about disruption, it may also be helpful to develop a more generic approach to concerns about uses and disruptions of planetary surfaces. As a first step towards framing generic guidelines for exploitative and other activities on planetary surfaces, there is a need to understand what kinds of activities will be involved, what types and scales of disturbances are likely to occur in the near- and longer-terms, and whether potential impacts are likely to be transient, cumulative or irreversible. Such information will be essential for the eventual drafting of protocols to identify and protect important resources— environmental, as well as historical, scientific or 'other' features of interest to humans. This presentation provides information on a preliminary study to categorize the nature and extent of proposed lunar exploration and exploitation activities in the coming decades and to construct a draft matrix and framework for considering how to balance stakeholders interests in exploring and using space resources. Such an approach could be helpful in examining the types of impacts or disruptions that might be important in different time frames, from pilot projects through scale up operation, on various planetary bodies with different characteristics.

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Human Exploration and Destination Drivers

Discoveries from the Lunar Reconnaissance Orbiter and Future Human Exploration of the Moon

Measurements from the Lunar Reconnaissance Orbiter (LRO) are providing answers to old questions, calling into question currently held beliefs, and raising new questions both in terms of science and exploration. Globally distributed meter-scale LROC images revealed a large population of young compressional scarps that were likely formed as molten portions of the core transitioned to solid, resulting in a negative volume change that put the brittle crust into a compressional state. These features are so young that is likely, if not certain, that large moonquake driven surface deformation occurs in the present era. Rather than clarifying the relative ages of late Copernican craters, LROC images call into question the relative significance of primary, secondary, and auto-secondary impacts and the effect of target strength (impact melt rocks, granular ejecta) on the cratering record. LROC images revealed over 75 occurrences of small (<5 km) young volcanic extrusions with ages proposed to be <200 my. Analysis of observations from LROC and Diviner revealed a previously unknown farside silicic volcanic center between Compton and Belkovich craters, far from any previously known domes or red spots. The age of this center is difficult to determine with accuracy due to its size and probable resurfacing events (pyroclastic?). Similar observations of the Lassell massif also raise the possibility of silicic explosive activity. Like its farside counterpart the age of terminal volcanic activity at Lassell is ambiguous. LROC observations led workers to question the current stratigraphic relations of touchstone basin-forming events (Imbrium, Serenitatis, Crisium), and thus the body of evidence for the late heavy bombardment. Observations with nearly every instrument onboard LRO show the poles to more enigmatic than previously thought. For the same crater some measurements indicate significant H deposits while others show no enrichment. Likely this conundrum is the result of depth sensitivity of the various measurements and a complex movement of volatile species within the regolith. Preparing for a human return to the Moon requires an exploration strategy to investigate key resource, engineering, and science questions. Precursor missions include polar landers with mobility to investigate distribution of volatiles. Simple yet capable long-lived rovers to measure, sample, and scout major geologic terrains. Sample return is required to test current hypotheses and calibrate the relative cratering record. These robotic missions feed into the decision process for selecting crewed targets, deliver samples to human exploration sites, and test technologies for missions to Mars. Early crewed missions will provide the means to unravel complicated geologic problems (i.e. complex silicic volcanism), test and implement resource utilization strategies, and provide the experience base to live and work on another planet. An exploration strategy of this scale is best carried out through close international cooperation implementing a sustainable plan robust to political winds.

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Human Exploration and Destination Drivers

Geological Field Activities at the HI-SEAS Planetary Surface Analog Mission Simulation in Hawaiʻi

The Hawaiʻi Space Exploration Analog and Simulation (HI-SEAS.org) program studies team function and performance on long duration exploration missions conducted in a remote habitat located on Mauna Loa, Hawaiʻi. The basaltic terrain and sparse vegetation of the site make it a good geologic analog to the Moon or Mars, and since the site is accessible year-round, it allows for longer-term isolation studies than other analog locations. HI-SEAS missions are comprised of six crewmembers who live in the habitat and interact with a mission support team remotely via an imposed 20-minute communications delay to provide Mars-like operational latencies. After a successful first mission lasting four months in 2013, NASA awarded HI-SEAS three years of additional funding to explore themes surrounding crew autonomy on missions of increasingly longer durations up to twelve months. The second four-month mission began on 28 March 2014.HI-SEAS crewmembers spend their time taking part in a number of research studies. Some of these activities require them to leave the habitat and conduct pedestrian extra-vehicular activities (EVAs) while wearing simulated space suits to approximate the encumbrances astronauts would face while conducting such excursions. One goal of HI-SEAS is to compare crew performance as missions increase in length, and to meet this objective a team of geologists works with a team of psychologists to develop geology-related tasks for the crew to complete in the area surrounding the habitat. The team-oriented tasks are designed to be gradable with quantifiable metrics so that meaningful conclusions about crew performance can be assessed.The tasks, which are given in the context of resource exploration and environment characterization, are presented in a progressive fashion so that each activity builds upon the previous one. First, features or areas of interest are identified in aerial imagery. The crew is then asked to scout these features on the ground and characterize their properties. This could take the form of measuring dimensions of a skylight, mapping flow units, collecting rock samples, or analyzing the samples using equipment in the habitat's laboratory. The HI-SEAS geology team evaluates how accurately the crew is able to accomplish these tasks compared with known values.

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POSTER

Human Exploration and Destination Drivers

Lung tissue exposure to Lunar Simulants

Lung tissue exposure to Lunar Simulants1Jillian C. Nissen, 2Martin A. Schoonen, 1Stella E. TsirkaRIS4E, Stony Brook University, 1Departments of Pharmacological Sciences, 2Geosciences, Environmental and Climate Sciences, Brookhaven National Lab.Future astronauts will be exposed to harsh environments with potentially harmful but unknown health effects. While some studies have been conducted on lunar materials, they failed to capture the full complexity of materials found on the moon. Lunar dust is extremely dry, exposed to space radiation and micrometeorite impacts, and can alter the surface of the material to result in greater reactivity in the lungs. Utilizing a set of materials that match not only the chemical composition of lunar dust, but also have been exposed to conditions similar to the space environment, we examine the effects of exposure of these samples on lung tissue. Utilizing ex vivo mouse lung organotypic slices, which accurately recapitulate not only the cell types present in the lung but also their tissue ratios and three-dimensional architecture, we assess changes in inflammatory markers, cell death, and reactive oxygen species generation through immunohistological and biochemical approaches. Control soils we have reported in the past are used as positive and negative controls.

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Human Exploration and Destination Drivers

ORAL

Incorporating Handheld Technology into Planetary Surface Exploration: Ongoing Testing and Further Studies

The next generation of planetary surface exploration will include the need for collecting valuable and diverse samples for return to Earth. While advanced traverse planning is crucial to mission success, the community must also work to develop a suite of in situ geochemical technologies for use in real-time sample high grading. One such instrument is the handheld x-ray fluorescence spectrometer (hXRF). Initially developed for use in industry and mining by companies such as Bruker, ThermoScientific, and Innov-X, we have subsequently tested this technology on a well-characterized suite of terrestrial geological samples in order to assess data return (data accuracy, precision and utility) and controlled field operations. Previous tests of this instrument also included testing on 18 lunar samples returned from the Apollo missions in order to investigate whether accurate and interpretable semi-quantitative data could be collected on the geochemically-complex lunar samples. While the initial instrument calibrations have been successful in proving the instrument's utility in unraveling the geochemistry of laboratory samples, the ultimate testing ground is deploying the hXRF in the field, preferably at a terrestrial analog site, in order to investigate the data quality of analyses completed in the field, and the utility of those data for understanding the geological history of the region or determining high priority samples for further study.Some initial field investigations were conducted in conjunction with the NASA Desert Research and Technology Studies (D-RATS) field tests. Manned crews traversed the San Francisco Volcanic Field, AZ, in habitat rovers designed to support their crews for multi-day geologic traverses. The crews collected samples from multiple lava flows in an effort to understand the eruptive history of the volcanic terrain. The hXRF has since been deployed on these samples and this instrument was able to differentiate between flows at a resolution not identified in the field by the crews. These results indicate that the hXRF could be a valuable addition to future planetary surface missions by providing increased contextual awareness of the field site. These studies also indicate a need for future development and testing of technologies like the hXRF in an effort to investigate critical features for a suite of instrumentation that would be deployed for characterization of SSERVI Target Bodies. In addition to technology selection and implementation, it is important to understand operational factors of such instruments and how the data will be presented and used by a human crew, a study goal that will be addressed by the SSERVI Remote, In Situ, and Synchrotron Studies for Science and Exploration (RIS4E) team.The RIS4E team plans to investigate instruments similar to the hXRF in geologic field investigations to quantitatively assess factors impacting data quality, field operations, and how the data are applied during mission operations. The field site where this instrumentation will be deployed is the December 1974 flow in Kilauea Volcano, HI. The RIS4E team seeks to constrain the variability of geochemistry and mineralogy across the field site using a suite of portable instrumentation.

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Invited

ORAL

Radar Reconnaissance of Near-Earth Asteroids

Radar is an extremely powerful astronomical technique for characterizing near-Earth objects and for refining their orbits. The Arecibo and Goldstone radars can image near-Earth asteroids (NEAs) with resolutions as fine as several meters, which greatly exceed the finest resolution available from any ground- or space-based optical telescope. Radar images reveal an object's size, shape, spin state, and features on its surface such as craters, valleys, ridges, and even boulders. Among NEAs larger than 200 m in diameter, radar imaging has revealed that ~14% are double and triple systems, that ~15% are contact binaries, and that objects with oblate shapes and boulders are relatively common. Two-thirds of binary and ternary systems have been discovered by radar. Radar can determine the masses of binary NEAs and, in some cases, solitary NEAs through detection of the Yarkovsky effect. Multiple opportunities for high-resolution radar imaging occur annually that yield images that are exceeded in resolution only by spacecraft flyby and rendezvous missions. Radar echoes from NEAs have revealed stony and metallic objects, featureless spheroids, shapes that are elongated and irregular, unconsolidated rubble piles, rotation periods ranging from a few minutes to several weeks, objects whose rotation is accelerating, non-principal axis rotators, and surfaces that are extraordinarily rough.Radar is invaluable for refining orbits of potentially hazardous NEAs. Range-Doppler measurements provide astrometry with precision as fine as 4 m in range and 1 mm/s in velocity, with a fractional precision that is orders of magnitude finer than with optical measurements. Radar astrometry can add centuries to the interval over which we can predict close Earth approaches and dramatically refines collision probability estimates based on optical astrometry alone. Radar astrometry regularly prevents newly-discovered objects from being lost.A sequence of radar images can be inverted to estimate an asteroid's 3D shape and spin state, which constrains its formation and evolution. This opens up a number of important geophysical investigations into the asteroid's dynamical environment that can be very useful for spacecraft planning and navigation. Radar observations have supported multiple spacecraft missions to asteroids and comets, such as NEAR-Shoemaker, Hayabusa, Rosetta, EPOXI, Dawn, OSIRIS-REx, and Chang'e 2. The Chang'e 2 spacecraft images of Toutatis in 2012 confirm large-scale attributes of the published radar model but also reveal regions where the radar-derived shape model can be improved. Radar observations regularly contribute to orbit refinement and physical characterization of potential targets for NASA's proposed Asteroid Robotic Retrieval Mission. The number of asteroids observed by radar at Arecibo and Goldstone has tripled in the last three years. Radar observations of near-Earth asteroids are occurring at a rate of about once every five days and are poised for an explosion of exciting results. The field is young and we continue to discover new things about the near-Earth population.

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Reconnaissance of a Human Exploration Target with the NEA Scout Mission

The Advanced Exploration Systems (AES) Division from Human Exploration and Operations Mission Directorate (HEOMD) assessed and selected the proposed the Near Earth Asteroid (NEA) Scout mission concept in September 2013. The primary purpose of this mission would be to demonstrate a capability for low cost precursor reconnaissance of prospective human exploration targets. This mission would approach and perform a slow flyby of a NEA from the Near-Earth Object Human Space Flight Accessible Targets Study utilizing a 6U Cubesat platform propelled by a 80 m2 solar sail and equipped with a visible camera with color filters. The current baseline target is 2012 UV136, an Apollo asteroid in the 20-50 meter size range. The proposed NEA Scout mission would be launched as a secondary payload on the Space Launch System (SLS) Exploration Mission 1 (EM-1), the first planned flight of the SLS and the second un-crewed test flight of the Orion Multi-Purpose Crew Vehicle.In the course of the mission, the NEA Scout spacecraft would obtain observations directly responsive to the strategic knowledge gaps for Human exploration that need to be retired; in particular, the target ephemeris, shape, rotational properties, spectral class, local dust and debris field, regional morphology, and regolith properties. Some of these properties would be directly inferred from medium-field imaging. Others, like surface stability and soil properties, would be inferred by high-resolution imaging helped by a strong theoretical science exploration framework that is currently developed in some of the Solar System Exploration Research Virtual Institute (SSERVI) nodes. The overall implementation of NEA Scout mission embraces the paradigm change offered by the Cubesat architecture that yield for low mission cost: use of off-the-shelf components and subsystems that are tailored for a long cruise in deep space. Solar sail propulsion offers navigation agility during the cruise for approaching the target. The mission would also leverage recent onboard science data processing progress as mission's limited resources require responsibility for key activities to be handled autonomously.The NEA Scout mission embodies the spirit of exploration with a bold approach to human accessible NEA target reconnaissance. By targeting a NEA smaller than 100 meters, the objectives of NEA Scout are also synergistic with other NASA interests, such as Planetary Defense and asteroid science. Acknowledgements: The NEAScout mission concept is being developed jointly between Marshall Space Flight Center, the Jet Propulsion Laboratory, Langley Research Center, Johnson Space Center, and Goddard Space Flight Center.

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Invited

Lunar Flashlight: Mapping Lunar Surface Volatiles Using a Cubesat

Water ice and other volatiles may be located in the Moon's polar regions, with sufficient quantities for in situ extraction and utilization by future human and robotic missions. Evidence from orbiting spacecraft and the LCROSS impactor suggests the presence of surface and/or near-surface volatiles, including water ice. These deposits are of interest to human exploration to understand their potential for use by astronauts. Understanding the composition, quantity, distribution, and form of water/H species and other volatiles associated with lunar cold traps is identified as a NASA Strategic Knowledge Gap (SKG) for Human Exploration. These polar volatile deposits could also reveal important information about the delivery of water to the Earth-Moon system, so are of scientific interest. The scientific exploration of the lunar polar regions was one of the key recommendations of the Planetary Science Decadal Survey. In order to address NASA's SKGs, the Advanced Exploration Systems (AES) program selected three low-cost 6-U CubeSat missions for launch as secondary payloads on the first test flight (EM1) of the Space Launch System (SLS) scheduled for 2017. The Lunar Flashlight mission was selected as one of these missions, specifically to address the SKG associated with lunar volatiles. Development of the Lunar Flashlight CubeSat concept leverages JPL's Interplanetary Nano-Spacecraft Pathfinder In Relevant Environment (INSPIRE) mission, MSFC's intimate knowledge of the Space Launch System and EM-1 mission, small business development of solar sail and electric propulsion hardware, and JPL experience with specialized miniature sensors. The goal of Lunar Flashlight is to determine the presence or absence of exposed water ice and its physical state, and map its concentration at the kilometer scale within the permanently shadowed regions of the lunar south pole. After being ejected in cislunar space by SLS, Lunar Flashlight deploys its solar panels and solar sail and maneuvers into a low-energy transfer to lunar orbit. The solar sail and attitude control system work to bring the satellite into an elliptical polar orbit spiraling down to a perilune of 30-10 km above the south pole for data collection. Lunar Flashlight uses its solar sail to shine reflected sunlight into permanently shadowed regions, measuring surface albedo with a four-filter point spectrometer at 1.1, 1.5 1.9, and 2.0 _m. Water ice will be distinguished from dry regolith from these measurements in two ways: 1) spatial variations in absolute reflectance (water ice is much brighter in the continuum channels), and 2) reflectance ratios between absorption and continuum channels. Derived reflectance and reflectance ratios will be mapped onto the lunar surface in order to distinguish the composition of the PSRs from that of the sunlit terrain. Lunar Flashlight enables a low-cost path to in-situ resource utilization (ISRU) by identifying operationally useful deposits (if there are any), which is a game-changing capability for expanded human exploration.

Author: ANTHONY COLAPRETE

Invited

ORAL

Resource Prospector: A lunar volatiles prospecting and ISRU demonstration mission

Over the last decade, a wealth of new observations of the moon has demonstrated a lunar water system dramatically more complex and rich than was deduced following the Apollo era. A variety of observations have indicated several possible reservoirs of water and other volatiles. These volatiles, and in particular water, have the potential to be a valuable or enabling resource for future exploration. NASA's Human Exploration and Operations Mission Directorate (HEOMD) Advanced Exploration Systems (AES) is supporting the development of the Resource Prospector Mission (RPM) to explore the distribution and concentration of lunar volatiles prospecting and to demonstrate In-Situ Resource Utilization (ISRU). The mission includes the RESOLVE (Regolith and Environment Science and Oxygen & Lunar Volatile Extraction) payload, a NASA developed rover, and a lander will most likely be a contributed element by an international partner or the Lunar Cargo Transportation and Landing by Soft Touchdown (CATALYST) initiative. The RESOLVE payload is designed to: (1) locate near-subsurface volatiles, (2) excavate and analyze samples of the volatile-bearing regolith, and (3) demonstrate the form, extractability and usefulness of the materials. RPM is being designed with thought given to its extensibility to resource prospecting and ISRU on other airless bodies and Mars.Temperature models and orbital data suggest near surface volatile concentrations may exist at briefly lit lunar polar locations outside persistently shadowed regions. A solar-powered lunar rover could be remotely operated at some of these locations for the 4-15 days of expected sunlight at relatively low cost. Given the rather short duration for which this lunar mission is being designed, prospecting for sites of interest needs to occur near real-time, making this much different than a Mars rover mission. To help map and locate potential water/ice and hydrogen-bearing compounds, RESOLVE incorporates two analytical instruments: neutron and near infrared (NIR) spectrometers. The neutron spectrometer will be used to sense hydrogen down to concentrations as low as 0.5WT% to a depth of approximately 80 cm. The NIR spectrometer, which includes its own light source, will look at surface reflectance for signatures of bound H2O/OH and general mineralogy and can be used in concert with a camera and drilling auger. Once an area of interest is identified by the neutron and/or NIR spectrometers, the option to capture drill cuttings is considered. The auger drill can excavate samples to a depth of 100 cm. Captured samples are analyzed for volatile content using an oven to heat the sample and a gas chromatograph/mass spectrometer/NIR spectrometer system to determine composition and amount. An ISRU demonstration of hydrogen reduction is also planned, which has the ability to extract oxygen from iron oxide in the lunar regolith to produce water. This process provides an alternative resource capability to polar volatilesThis presentation will describe the Resource Prospector mission, the payload and measurements, and concept of operations.

SSERVI-ESF14-154

Author: RICHARD ELPHIC

ORAL

Invited

Barnstorming the Moon: Adventures of the Lunar Atmosphere and Dust Environment Explorer

The Lunar Atmosphere and Dust Environment Explorer (LADEE) was launched from Wallops Flight Facility on 6 September, 2013 aboard the very first Minotaur V, a Peacekeeper ICBM converted to civilian use. The launch was perfect, and LADEE entered lunar orbit on 6 October, 2013. In the following weeks, the first laser communications from deep space achieved 622 Mbits/sec downlink, paving the way for a revolution in space communications. Following instrument checkout and commissioning, LADEE commenced science operations on 21 November, 2013. Over the next 100 days, LADEE's Ultraviolet/Visible Spectrometer (UVS) systematically mapped sodium, potassium and other species in the tenuous lunar exosphere, while the Neutral Mass Spectrometer (NMS) systematically mapped argon, helium, and discovered neon in the lunar exosphere. At the same time, the Lunar Dust EXperiment (LDEX) discovered and characterized the dust exosphere, caused by continual bombardment of the Moon's surface by micrometeoroids. After the nominal science mission, LADEE continued to acquire more science data, culminating in a set of observations at very low altitudes (<10 km) above the sunrise terminator. Data from UVS show that the Moon's sodium exosphere varies with lunar phase, with density increasing as the Moon waxes toward Full then falling after. An additional wrinkle on this behavior is the apparent reduction in sodium while the Moon is in the Earth's geomagnetic tail, suggesting that sodium production is diminished when out of the solar wind. Potassium and other metals show variations on this behavior, including responses to meteoroid streams, particularly the Geminids. NMS mapping of argon-40, a constituent arising from potassium-40 decay in the lunar interior, shows that the gas "freezes out" on the very cold lunar nightside (~100K), but produces a dawn bulge of enhanced density as the cold lunar surface rotates around into sunlight and warms up. While this behavior was seen in Apollo data, and modeled, NMS has observed new twists to this basic surface boundary exosphere process. NMS also observed helium and found a relationship with the He++ being delivered to the Moon by the solar wind. LDEX has mapped out the height- and local time dependence of the tenuous lunar dust veil, finding that dust densities are highest on the ram side of the Moon, facing the direction of motion of the Earth-Moon system around the sun. This much may be expected, but LDEX is revealing surprising new features. Occasionally, LDEX observes a large, short-term (less than a few minutes) increase in dust density. Evidently this is due to the impact of much larger meteoroids within a few minutes and tens to 100s of kilometers of LADEE. This talk will describe the mission and set the stage for talks by the science team members.

Author: JASPER HALEKAS
ORAL

Invited

The Latest From ARTEMIS

The two ARTEMIS probes continue their successful extended mission around the Moon, studying the interaction of terrestrial and solar plasma with the lunar environment, and serving as a solar wind beacon. ARTEMIS provides continuous monitoring of the incoming plasma, including protons and doubly ionized helium (alpha particles) in the solar wind, and magnetospheric plasma during the Moon's passage through the geomagnetic tail. These ARTEMIS observations are critical to developing a complete understanding of the dynamics of the complex neutral exosphere recently revealed by LADEE. The highly variable plasma influx directly supplies a portion of the lunar exosphere, most notably helium. The flowing plasma also liberates other exospheric species from the surface through charged particle sputtering, and acts as the final sink for a large proportion of the exosphere, by picking up ionized constituents and sweeping them away from the Moon. Incoming plasma also contributes to weathering of the surface, with the plasma contribution to space weathering (as well as solar wind sputtering) reduced in regions with strong intrinsic magnetic fields, where a significant fraction of the incoming plasma reflects before reaching the surface. ARTEMIS observations cast new light on the physics of the plasma-magnetic field interaction, with implications for both the surface and the exosphere. In concert with LADEE and LRO, the ARTEMIS probes help provide a complete picture of the coupled plasma-surface-exosphere system.

Author: AMY MAINZER

ORAL

Invited

Exploring the Near-Earth Objects with NEOWISE

The NEOWISE project is returning radiometrically derived diameters and albedos for minor planets, including near-Earth objects (NEOs). Using the Earth-orbiting Wide-field Infrared Survey Explorer telescope, NEOWISE measurements have been used to set constraints on the numbers, orbits, and physical properties of asteroid and comet populations. To date, more than 700 NEOs have been observed by NEOWISE, with more to come from mining of the archival data. By virtue of observing in the infrared near 90 degrees solar elongation, NEOWISE-detected NEOs are more likely to be large, and a larger fraction of them are potentially hazardous compared to the sample detected by ground-based telescopes observing near opposition. Population studies have shown that the NEO albedo distribution remains approximately constant with diameter down to the limit of the infrared-selected sample, 100 m. Recent results have shown that NEO albedos become brighter below this size limit, but as this sample is optically-selected, discovery biases against small, dark objects become strong and cannot be easily disentangled. The goal of the recently reactivated NEOWISE mission is to continue physical characterization of NEOs, resulting in measurements of diameters and albedos for close to 2000 objects over the course of its 3 year survey. NEOWISE data have enabled a wide range of solar system studies, including long- and short-period comets, Main Belt asteroids, Jovian Trojans, and Hildas, as well as the discovery of the first known Earth Trojan asteroid. Combining infrared data with shape models and rotational states determined from radar, in situ spacecraft visits, or optical lightcurves provides a powerful means for constraining properties such as thermal inertia. The NEOWISE project serves as a pathfinder for future space-based NEO discovery and characterization efforts such as the Near-Earth Object Camera (NEOCam). NEOCam builds upon the knowledge gained from NEOWISE and will significantly expand the sample of NEOs with well-determined orbits and sizes, including those that may serve as the best potential destinations for future exploration. This publication makes use of data products from the Wide-field Infrared Survey Explorer, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration. This publication also makes use of data products from NEOWISE, which is a project of the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration.

Author: HONG-KYU MOON

POSTER

Invited

The DEEP-SOUTH: Round-the-clock Census of NEOs in the Southern Hemisphere

Korea Astronomy and Space Science Institute started a project to build a network of wide-field optical telescopes called the KMTNet (Korea Micro-lensing Telescope Network) in 2009. The KMTNet consists of three identical 1.6-m prime focus optics and 18K_18K mosaic CCD cameras that results in 2_2 degrees field of view with a delivered image quality less than 1.0 arcsec FWHM under atmospheric seeing of 0.75 arcsec. These telescopes will be located at CTIO in Chile, SAAO in South Africa, and SSO in Australia. This network of telescopes will be partly used for "Deep Ecliptic Patrol of the Southern Sky (DEEP-SOUTH)" as a one of such secondary science projects. The three stations are longitudinally well separated, and hence will have a benefit of 24-hour continuous monitoring of the southern sky. The wide-field and round-the-clock operation capabilities of the facility are ideal for discovery and physical characterization of asteroids and comets. Based on time series observations with the KMTNet, orbits, absolute magnitudes (H), spin states, shapes and activity levels of asteroids and comets including NEOs will be systematically investigated at the same time. Their approximate surface mineralogy will also be discriminated using SDSS and Johnson Cousins BVRI colors. The first KMTNet telescope in CTIO will be put into operations in June 2014 and the whole network is expected to be on-line in late-2014.

Author: CHRISTOPHER RUSSELL
ORAL

Invited

The Smallest Terrestrial Planet Seen in the Light of Dawn

Kepler, Titius, Bode and von Zach were certain that a planet lay between Mars and Jupiter, a conviction that was confirmed with the discovery of Ceres on January 1, 1801. However, Ceres was very small and, even when combined with the mass of Pallas, Juno and Vesta, discovered later, they were dwarfed by the other planets. Thus, these bodies were demoted to 'minor planet' status and later to 'asteroid' status. Only recently was Ceres, the largest of these bodies, 'raised' to dwarf planet status. But what really defines a planet? Can a planet be defined by its surroundings, or is it an essence from within, as Klaus Keil implied with his sobriquet for Vesta, "the smallest terrestrial planet"? Dawn orbited Vesta for over a year with cameras, spectrometers, and radiometric tracking. It confirmed our zeroth-order expectations that Vesta was the parent body of the howardite, eucrite and diogenite meteorites. Dawn showed the ravages inflicted by the collisional environment of the asteroid belt as Jupiter formed and the outer planets migrated. But Vesta is not a simple battered rock. It is a largely intact protoplanet that underwent igneous differentiation, similar to the terrestrial planets. While much of the structure on the surface of Vesta results from exogenic processes, there is also evidence for endogenic processes, possibly recently in geologic history. Curvilinear gullies in crater walls suggest that the crater forming event resulted in the release of flowing water into the crater contributing to the formation of pitted terrain on the floors of these craters as the floor devolatilized. At a minimum the gullies and pitted terrain suggest the presence of ice locked up in some regions of Vesta's crust. Impacts could produce transient atmospheres and transient flows on the surface. These may have been produced as recently as 50 Ma ago. Vesta, if judged from the processes occurring on the surface and below, very strongly deserves Klaus Keil's sobriquet.

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Author: KEITH BENNETT

POSTER

Missions (Including Commercial)

ACCESSING PDS DATA IN PIPELINE PROCESSING AND WEB SITES THROUGH PDS GEOSCIENCES ORBITAL DATA EXPLORER'S WEB-BASED API (REST) INTERFACE

ODE Overview: The Orbital Data Explorer (ODE) is a web-based search tool (http://ode.rsl.wustl.edu) developed at NASA's Planetary Data System's (PDS) Geosciences Node (http://pds-geosciences.wustl.edu/). Through ODE, users can search, browse, and down-load a wide range of PDS Mars, Moon, Mercury, and Venus data (A detailed list of current ODE holdings can be found at http://wufs.wustl.edu/ode/odeholdings/index.html).In the fall of 2012, the Geosciences node introduced a simple web-based API that allows non-PDS web and processing tools to search for PDS products, obtain meta-data about those products, and download the products stored in ODE's meta-data database (http://oderest.rsl.wustl.edu/live). The first version is now used by several teams in periodic processing and web sites.REST Interface Overview: The ODE Representational State Transfer (REST) interface is a simple web-based interface allowing external users and tools to access the ODE metadata and products. REST query. The current ODE REST interface only supports read-only GET functions. The query format basically breaks down into several components including target, query type, output format, and query parameters. A simple query will return a variety of data such as a list of products, product metadata, product footprints, product browse images, or even the products themselves. Results are typically in XML or JSON format except in cases where the return is an image. Product file requests return one or more web-addresses for directly downloading the file(s). Example. A simple example of using the REST interface to find how many HiRISE Version 1.1 RDR products exist within a latitudes 0 to 10 and longitudes 0 to 10: http://oderest.rsl.wustl.edu/live?target=mars&query=products&results=c&iid=HIRISE&pt=RDRV11&maxlat=10.0&minlat=0.0&westernlon=0.0&easternlon=10.0 Returns (formatted for readability):<ODERsults><Status>Success</Status><QuerySummary><Date>2013-12-18T09:07:08.197</Date><target>MARS</target><query>PRODUCT</query><westernlon>0</westernlon><easternlon>10</easternlon><minlat>0</minlat><maxlat>10</maxlat></QuerySummary><Count>353</Count></ODEResults>REST Product Queries: The ODE REST interface allows external tools to query ODE for a wide range of data including product metadata. Product metadata, which varies depending on the data set, includes observation times, creation times, map resolutions/scales, observation angles, solar longitudes, solar distances, spacecraft clock times, version numbers, activity ids, producer information, and links to instrument web sites. Queries can be limited by instrument hosts, instruments, product types, data set ids, location, features, observation times, and creation times. Location limits can be based on the "intersecting", "contains", or "contained by" geographic relationships between products intersecting a surface lat/lon bounding box or footprint. Using a series of queries can produce a very sophisticated result that find spatial and temporal relationships between various products.Comments on ODE and questions on REST access can be sent to bennett@wustl.edu.

Author: ROBERT CATALDO
ORAL

Missions (Including Commercial)

Low-Power Radioisotope Power Systems for Future Smaller Spacecraft and Low-Cost Missions

Low-Power Radioisotope Power Systems for FutureSmaller Spacecraft and Low-Cost MissionsBackgroundRadioisotope Power Systems (RPS) have enabled many NASA missions during the past 50 years to very harsh and challenging destinations of the solar system, from the Moon to the solar heliosphere to interplanetary space, supplying both electrical energy and useful heat. An RPS utilizes the heat generated from natural decay of plutonium-238 via heat-to-electric conversion devices. In particular, the long 87.8-year half-life decay of Pu-238 and the robust nature of thermoelectric devices allow long-lived missions, such as experienced with the Voyager 1 and 2 spacecraft, both still operating more than 35 years after launch. Additionally, the power system essentially supplies its own energy source, making it enabling for missions with destinations far from the Sun or on planetary surfaces, immune from occultation caused by clouds, dust or planetary surface features.All past NASA RPS missions have used radioisotope thermoelectric generators (RTG) that typically utilize a series/parallel combination of thermoelectric elements for heat to electric conversion. The current thermoelectric technology employed, such as the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG), has an efficiency of approximately 5.0%, producing 110 We from 1,975 Wth. However, mission concepts that would utilize a large RTG or multiple RTGs are typically larger spacecraft and certainly more costly, with a lower frequency of occurrence. Over the past several years, smaller and less costly spacecraft concepts have been discussed that could provide a higher rate of interesting missions envisioned by the science community.IntroductionTo this end, the Radioisotope Program Office at the Glenn Research Center is exploring the science mission needs for low-power RPS <1.0 We. The more recent interest and developments in small spacecraft that could ride share on other larger missions for example, has a potential need for the low-power RPS. One potential low-power RPS would utilizes the flight-proven (e.g., Cassini, MER rovers) Radioisotope Heater Units (RHUs), which produce approximately 1.0 Wth with 2.7 gm PuO2. Concepts have been developed using a single and multiple RHUs. The single RHU-RPS engineering unit was developed by Hi-Z Inc., built and tested for high "g" applications required for previously proposed Mars penetrator missions. Other concepts were investigated that used multiple RHUs that could produce electric power approaching 0.5 We with 10 RHUs. Therefore flexibility exists to tailor such designs. In addition, these systems could be electrically placed in parallel to match spacecraft power system requirements.In addition to continuous power output, the RHU-RPS would also serve to provide heat to critical spacecraft components and instruments, thus allowing a potentially simpler thermal management system envisioned for a small, low-cost spacecraft.

Author: YOUNG-JUN CHOI
ORAL

Missions (Including Commercial)

Scientific Aspects for Korean Lunar Exploration

Korea is going to launch the first orbiter in 2017 and both orbiter and lander around 2020 for lunar exploration. Since the surface of the Moon has been a witness of the Solar System history, currently lunar whole surface map in visible spectral range was completed through a camera of the latest lunar missions. However, because lunar surface continuously changes by impacts of meteorites, the surface should be observed again. In addition, it would be useful to use multi-wavelength polarimetry in visible range or to measure surface reflectance in ultraviolet spectral range. Polarization of lunar surface depends on both albedo and surface roughness, which is related to thermal properties results from infrared (IR) observation. Further IR observations are required for studying mineralogy and confirming the existence of water ice at permanent shadow region in both poles. IR spectral range for scientific study of lunar surface is classified as three regions according to recently results of the study. In the first range, 0.5-1.5_, absorption lines of Olivine, Pyroxene can be detected. Water, ice, OH absorption lines can be detected in 2.6-3.6 _range. Christian Feature (CF), in 7-9 _ range, shows silicate mineralogy. We will briefly discuss about current Korean lunar exploration status and its scientific aspects.

Author: PAMELA CLARK

ORAL

Missions (Including Commercial)

LunarCubes: Progress on LWaDi orbiter

We are in the process of developing a payload and bus concept for high priority science-driven missions of lunar exploration using an architecture known as LunarCube, with focus on resolving the challenges of using a standardized platform and existing cubesat hardware and maintaining a cubesat form factor for CubeSats missions to operate near or on the Moon. We focus on architecture for lunar exploration because of its proximity and accessibility as a stepping stone to the rest of the solar system, combined with the great international scientific interest in the Moon and its suitability as an analog with extreme range of conditions and thus an ideal technology testbed for much of the solar system.Three concepts are under consideration, including a lunar polar outflow impactor, an observatory pathfinder, and a lunar orbiter. Here, we focus on LWaDi (Lunar Water Distribution) orbiter. The goal of LWadi is to determine the nature of lunar water and water component distribution as a function of time of day, latitude, and regolith composition. The payload is a compact broadband IR detector with measurement capability inclusive of the 1.3 to 3.7 micron range and high spectral resolution (10 nm), capable of distinguishing the many features associated with water and water components in various forms, as well as mineral signatures, associated with this region. The instrument, with heritage from OSIRIS-REX OVIRS, has compact optics that include a linear variable filter and an adjustable iris to maintain a 10 km spot size regardless of altitude and a built in cryocooler to maintain the detector at 140K. The instrument package is approximately 1.5U and 2 kg. The high inclination, highly elliptical (7 hour) equatorial periapsis orbital trajectory is designed to provide repeated coverage of the same representative selected surface features at different times of day (from dawn to dusk) for each lunar cycle. We have completed preliminary system definition and design activities. The result is a 6U concept which includes state of the art components, including the GSFC SpaceCube Mini C&DH and INSPIRE X-band communication system. Other components, developed for LEO cubesats, will need to be modified as necessary to provide radiation mitigation required for deep space operation. Thermal modeling indicates we should be able to maintain the temperature inside the spacecraft between 7 and 29 degrees, and with additional thermal shielding, to maintain the optics box below 240K. We are initiating thermal and vibrational testing of a breadboard representing the payload under the range of conditions that would be experienced in lunar orbit. Our long-term goal is cost-effective, generic design for a broad cross-section of future high priority space or surface payloads for planetary, heliophysics, and astrophysics disciplines.

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Author: PAMELA CLARK

POSTER

Missions (Including Commercial)

Compact and/or Cryogenic Lunar Surface Packages

Much smaller bodies orbit most stars, thus planets and not stars are the most common bodies in the universe. Solid body formation and modification processes are a key to understanding cosmic processes: the new cosmology. Volatiles, including water and simple organics and their ices, are unexpectedly ubiquitous on the surfaces of Mercury and the Moon, especially at their poles, as well as asteroids. Implications are that surface processes involving interactions of volatiles with space radiation, dust and charged particles are playing important roles in surface processes and potentially in regolith and planetary formation, influencing processes ranging from space weathering to accretion to biological precursor formation. The development of instrument packages capable of continuous operation on planetary surfaces is critical for understanding these processes.In support of Project Constellation, we developed a concept for an ALSEP-like stand-alone lunar surface instrument packages without dependence on radioisotope-based batteries: LEMS (Lunar Environmental Monitoring Station). And initial attempt to design an environmental monitoring package conventionally with a solar/battery based power system led to a package with a unacceptably large mass (500 kg) of which over half was battery mass. We eventually reduced the mass to 100 kg using radiation hard, cold temperature electronics, innovative thermal balance strategies using multi-layer thin reflective/insulting materials, a gravity-assisted heat pipe, and a limited night time duty cycle (Clark et al, 2011). Using existing cubesat components battery technology, similar thermal/mechanical, compact versions of several instruments, we estimate a 12U concept for such stations with 4-5U for payload.Major challenges in developing such systems remain, however, particularly in regard to thermal design and power storage. Recently developed thermal protection technologies such flexible polymer aerogel, more compact heat pipes utilizing ionic liquids, more efficient, radiation and thermal degradation tolerant solar panels may improve thermal protection with lower mass and volume penalty. However, the biggest challenge is in energy storage without the use of RTGs, which so far has been met by limiting power consumption through hibernation or the limited duty cycle presented here. The use of RTGs, with their limited availability and high cost, is far from an ideal solution. The biggest potential may lie in High Temperature Superconductors, now being used in power generation, storage, and transmission here on Earth. HTS systems should be scalable in theory.

Author: RUSSELL COX
ORAL

Missions (Including Commercial)

LunarCube Based Transient Asteriod and Planetesimals (TAPs) Observatory

Resent calculations by Bill Bottke of Solar System Exploration Research Virtual Institute (SSRVI) suggest that there may be as many as ten to twenty, one to two meter sized asteroids entering the Earth - Moon system each year. Many of these bodies may be temporarily captured for several weeks or months in chaotic trajectories that are likely to be energetically close to the Earth-Moon Lagrange points affording an opportunity for rendezvous and interaction several times each year with a previously unobserved population of Near Earth Objects (NEOs). This presentation will outline an observation program consisting of several generations of increasingly complex ESPA Ring Carrier \ iCubeSat platforms capable of interacting with 50 to 100 NEOs over a ten to fifteen year timeframe. The proposed architecture would place an ESPA based carrier at an Earth - Moon Lagrange point with ten to twenty iCubeSat based chaser spacecraft. The carrier would provide propulsion, power, communication, navigation and computational support until a reachable NEO is detected and an individual chaser is launched, then the chaser must be able to track and rendezvous with a one meter sized object in a nearby chaotic trajectory. This rendezvous capability will be critical for future crewed and uncrewed missions to NEOs. Each chaser iCubeSat would have its own instrument suite that would include penetrators or robot arm(s) to interact with the object to ascertain its chemical and physical properties. Ideally one would launch 3 to 5 carriers over a ten to fifteen year timeframe to take advantage of improving technology and knowledge of the NEO population to be studied.The knowledge gained would be very valuable to both the planetary science and asteroid mining communities. One simple and critical observation that can only be made by an architecture like this is to understand the relative abundance of differing asteroid morphologies. It is believed that asteroids have internal structures ranging from solid rocks to rubble piles to “dust bunnies” and very likely the only way to distinguish between these cases and to get good statistics on their relative abundances among NEOs and asteroids would be to directly interact with tens or hundreds of individual bodies. Additionally, “dust bunnies,” if they exist, would very likely be good analogs or examples of the earliest objects that became planetesimals in the early accretion disk and very little is known about the first stages of aggregation in planetary formation.

Author: RUSSELL COX
ORAL

Missions (Including Commercial)

The International Lunar Geophysical Year: 2017-2018

The Lunar Renaissance 2007 - 2020: Starting n 2007 eleven spacecraft from many countries transformed our understanding of the Moon reveling a dynamic destination rich with new scientific and commercial opportunities that can unlock the entire solar system for all mankind. In 2017 - 2018, Russia, China, Korea and the US all plan to have active national missions in cislunar space. There are as many as twenty or more private missions being planed and there will be many secondary payloads and LunarCube missions riding along. Thus, there are going to be many nations, many organizations and many, many people involved in active missions in Cislunar space in the eighteen months from July 2017 to December 2018 the 60th anniversary of the International Geophysical Year 1957 - 1958. Proposal: We are proposing to create The International Lunar Geophysical Year 2017 - 2018 (ILGY) to coordinate many of these activities. Like the International Geophysical Year (IGY) of 1957 - 1958, that launched the space age, the ILGY will focus on joint scientific collaboration and coordination while setting the stage for future political and commercial cooperation that will be critical for the peaceful and profitable exploration and exploitation of the cislunar environment for all mankind. Initial Activities in 2014: Flexure Engineering and The Select Investor, Inc. will be providing the initial organization and promotion of the ILGY providing many opportunities for collaboration and discussion through the Lunar Intiatives..The Lunar Initiatives•The Lunar Workshops•The Lunar Special Interest Groups (SIGs)•The Lunar Challenges•The Lunar Incubators•The International Lunar Geophysical Year In addition, we will create a public clearing house on the internet for missions, instruments and scientific objectives expected to be operational in the ILGY timeframe.We will be establishing and running the monthly ILGY SIG that will explore these themes : Scientific Collaboration•Active Missions \ Scientific Objectives•Terrestrial Scientific Collaborations•Future Missions \ Scientific ObjectivesMission and Organizational Coordination•National Missions•Private or Commercial Missions•Terrestrial OrganizationsPolitical, Legal and Standards •Treaties and other mechanisms to ensure open access for all mankind•Legal framework for scientific and commercial activities•Technical standards to encourage coexistence, interoperability and reuseActivities in 2015 - 2016: Our goal will be to provide the information we have collected and the support systems we have created through The Lunar Initiatives to existing international political, professional and standards bodies to help in the creation of collaborative, coordinated strategies to deal with the tsunami of activity that is building now and will crash onto the Lunar shores in the second half of this decade. Conclusions: The Lunar Renaissance is underway. The ILGY would help smooth and accelerate global collaboration and exploration providing scientific and commercial benefits for all mankind.

Author: BRIAN DAY
POSTER

Missions (Including Commercial)

Ground-Based Lunar Meteoroid Impact Observations and the LADEE Mission

What was once thought a spurious phenomenon with little scientific evidence - a form of Transient Lunar Phenomena, point flashes from lunar meteoroid impacts are now a relatively commonly observed phenomenon as shown by the many confirmed observations by both professional and amateur groups. In addition to the natural phenomena, several artificial impacts of spacecraft on the moon over the last fifteen years have yielded valuable information on the physics of impacts as well as evidence of sub-surface water ice. A coordinated effort between NASA and ground-based observers was recently undertaken to assist in the scientific efforts of NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) mission. These efforts involved observers from around the world. They yielded geographic and temporal coverage that expanded upon and supplemented that which was provided by the Automated Lunar and Meteor Observatory (ALaMO) operated by NASA's Meteoroid Environment Office (MEO). They resulted in confirmed recordings of lunar meteoroid impacts during the LADEE mission that were not observable by ALaMO.Among the data collected by LADEE during the science phase of its mission is that of the presence of lunar dust aloft, along with changes in the dust's concentration, thought to be indicative of "flak" from meteoroid impacts. The lunar environment provides an excellent laboratory to study phenomena related to hypervelocity impacts, and correlations between ground-based observations of lunar impacts and in situ measurements of changes in dust concentration have the potential to contribute valuable information on the physics of hypervelocity impacts. Collaboration between the LADEE mission personnel and ground based observers equipped for the task is an excellent example of professional-amateur collaborations. As part of this campaign, NASA's Solar System Exploration Research Virtual Institute (SSERVI) conducted an online "Workshop Without Walls" for interested parties from around the world to outline the plans and procedures for making scientifically useful observations. This workshop brought together members of the LADEE mission, MEO, the Association of Lunar and Planetary Observers, and a number of experienced impact observers. The workshop was recorded and archived by SSERVI to be used as a resource for continued professional-amateur collaborations in lunar meteoroid impact studies during and continuing beyond the LADEE mission.

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Missions (Including Commercial)

Next-Generation Laser Retroreflectors for Solar System Exploration, Geodesy and Gravitational Physics

We are developing next-generation laser retroreflectors for solar system exploration, geodesy and for the precision test of General Relativity (GR) and new gravitational physics: a micro-reflector array (INRRI, Instrument for landing-Roving laser Retroreflectors Investigations), a midsize reflector array, CORA, a large single, large retroreflector (MoonLIGHT, Moon Laser Instrumentation for General relativity High accuracy Tests). They will be fully characterized at the SCF_Lab (Satellite/lunar/gnss laser ranging and altimetry Characterization Facilities Laboratory), a unique and dedicated lab infrastructure of INFN-LNF, Frascati, Italy (www.lnf.infn.it/esperimenti/etrusco/). Research program:1. Laser retroreflector devices to determine landing accuracy, rover positioning during exploration and planetary/moons surface georeferencing. These devices will be passive, wavelength-independent, long-lived reference point enabling the performance of full-column measurement of trace species in the Mars atmosphere by future space-borne lidars. These measurements will be complementary to highly-localized measurements made by gas sampling techniques on the Rover or by laser back-scattering lidar techniques on future orbiters and/or from the surface. INRRI will also support future science experiments of quantum physics laser communications exploiting the polarization states of laser photons, carried out among future Mars Orbiters and Mars Rovers. This will be possible also because the INRRI laser retroreflectors will be metal back-coated and, therefore, will not change the photon polarization. The instrument is also being proposed for landings on the Moon (two Google Lunar X Prize Missions, namely Moon Express and Astrobotic). The added value of INRRI is its low mass, compact size, zero maintenance and its usefulness for any future laser altimetry, ranging, communications, atmospheric lidar capable Mars orbiter, for virtually decades after the end of the Mars surface mission, like the Apollo and Lunokhod lunar laser retroreflectors.2.Tests of GR with LLR on MoonLIGHT reflector (see abstract of D. Currie)3.Extension of program to:•Mars, Phobos and Deimos•Jupiter and Saturn icy/rocky moons•Near Earth Asteroids4.Development of new gravitational physics models and set experimental constraints using also laser ranging and laser reflectors in the solar system:•Extension of General Relativity to include Spacetime Torsion•Non-Minimally Coupled (NMC) Gravity, non minimal coupling between matter and curvature (so-called f1+f2 theories)5. Strong synergism with:•Ground stations of International Laser Ranging Service (Apache Point Lunar Laser-ranging Operation, in the US; MLRO, Matera Laser Ranging Observatory in Italy)•Data Laser-Comm.; mining of moons and asteroids•Search for exolife on Jupiter/Saturn moons.

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Missions (Including Commercial)

The Solar Scout: A Solar Sail Asteroid Prospector

Asteroid mining will require the direct, in situ, prospecting of Near Earth Objects (NEO). An ideal asteroid prospector would be able to visit a number of mining candidates in sequence, each requiring a substantial velocity change, typically several km / second for each new NEO. A Solar Sail, which requires little or no expendable propulsion, is the natural choice for an asteroid prospector, as fuel constraints would severely limit the number of asteroid candidate visits possible using chemical or ion propulsion. This talk will describe the Solar Scout™, a solar sail spacecraft intended for asteroid prospecting. The current spacecraft design has a mass of < 60 kg, a sail extent of 40 x 40 meters and a nominal payload mass of 5 kg. With a Solar Sail for propulsion, the Solar Scout could visit between one and two mining candidates per year, depending on the velocity change required and the duration of each asteroid rendezvous.The Solar Scout payload would include a a visual camera, for near-rendezvous optical navigation, and one or more sail cameras (for monitoring wrinkles and billows in the sail). Potential instruments include a magnetometer (for the detection of metals), infrared spectrometers (to distinguish between different geological materials), and Asteroid Radio Tomography (ART, a passive or active system for detecting internal water and buried objects). To save weight, these instruments would be integrated into the sail structure (i.e., the magnetometer would be located at a sail vertex, and the ground penetrating radio antennae could use the sail as a ground plane. Other instruments (such as gamma ray backscatter detectors) would likely not fit within the instrument mass and power budgets. The results from a NEO prospector would certainly be of scientific interest; as is common in geophysical prospecting; Asteroid Initiatives intends to seek arrangements with NASA allowing for the immediate release of a portion of the data acquired to the scientific community.

Author: BENJAMIN GREENHAGEN

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Missions (Including Commercial)

The Extreme Thermal, Thermophysical, and Compositional Nature of the Moon Revealed by the Diviner Lunar Radiometer

After nearly five years in operation, and well into its extended science mission, the Diviner Lunar Radiometer has revealed the extreme nature of the Moon’s thermal environments, thermophysical properties, and surface composition. This presentation will highlight contributions from members of the Diviner Science Team addressing a diverse range of scientific questions from the extended science mission.Diviner is the first multispectral thermal-infrared instrument to globally map the surface of the Moon. To date, Diviner has acquired observations over nine complete diurnal cycles and five partial seasonal cycles. Diviner daytime and nighttime observations (12 hour time bins) have essentially global coverage, and more than 80% of the surface has been measured with at least 6 different local times. The spatial resolution during the mapping orbit was ~200 m and now ranges from 150 m to 1300 m in the current elliptical “frozen” orbit. Calibrated Diviner data and global maps of visible brightness temperature, bolometric temperature, rock abundance, nighttime soil temperature, and silicate mineralogy are available through the Planetary Data System (PDS) Geosciences Node.Diviner was designed to accurately measure temperatures across a broad temperature range from midday equatorial regions such as the Apollo landing around 400K, typical nighttime temperatures of less than 100K at night, and extreme permanent shadowed regions colder than 50K. The coldest multiply-shadowed polar craters may have temperatures low enough to put constraints on lunar heat flow. Diviner data have also been used to estimate the thermal properties of non-polar permanently shadowed regions.Diviner is directly sensitive to the thermophysical properties of the lunar surface including nighttime soil temperature, rock abundance, and surface roughness. During the extended science mission we have produced higher fidelity maps of these properties and used them to investigate anomalous rock abundances, “cold spots” with fluffier surface layers, regolith formation and evolution, and surface roughness.Diviner was designed to characterize the Christiansen Feature (CF) and constrain lunar silicate mineralogy. Recent efforts in this area have focused on improving the quality of Diviner’s mid-infrared “photometric” correction, groundtruthing Diviner observations to Apollo soils, using Diviner’s longer wavelength channels to improve constraints on olivine, and combining Diviner with visible and near-infrared datasets to enhance interpretations of pyroclastic deposits, plagioclase-rich regions, high silica regions, and space weathering.A major effort during the extended science mission has been to create a “Foundation Dataset” (FDS) to improve the quality and usability of Diviner data available in PDS. To improve the radiometric accuracy, we reexamined Diviner’s pre-flight ground calibration and revised the in-flight calibration methodology. Diviner level 1b activity and quality flags have been modified based on critical reviews from Diviner data users. Finally, we used the new level 1 data to produce a wide range of level 2 and 3 gridded datasets that are more accurate, better organized, and include important geometric and observational backplanes. Delivery of the Diviner FDS to PDS is expected to begin in 2014.

SSERVI-ESF14-170

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Missions (Including Commercial)

ANALYTICAL EXPLORATION OF MANNED SPACE MISSION TO HELIOPAUSE

One of the most important things for the development of mankind is the various advancements in space technology. This is essential, as advancements in space technology have also opened up new frontiers in the development of our modern world as well. Everything that we learn from our universe has been utilized in some way of advancing our technology in our everyday lives as well. Each step in space exploration, takes humanity closer to the brink of significant advancement. Hence, the next logical step in space exploration would be to start exploring the outer fringes of our solar system. The outer boundaries of the solar system will provide the space programs of the world with enough data, so that advanced interstellar exploration may become a reality some day. However, reaching the outer solar system has its challenges as there would be a lot of problems associated with navigation, communications, power requirements, radiation shielding, life support planning as well as many other logistical problems which need to be solved before it would be possible to plan such a long range mission. This paper explores the aspect of an unmanned mission to the Heliopause which is considered as the outer boundary of the solar system along with a stopover at Pluto. The paper discusses the available nuclear technology of today in order to create a feasible mission plan to the Heliopause. Technology which is readily available today for a manned mission as well as for an unmanned mission is discussed as a case study and simulations have been used to strengthen the case. Moreover, this paper hopes to establish a precedence for an interstellar mission that can take the case study of this mission to the heliopause at least as a starting point in technological planning.

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Missions (Including Commercial)

The Utilization of Robotic Space Probes in Deep Space Missions: Case Study of Nuclear Power Requirements

The exploration of space is a driving force for mankind for understanding the universe. However, due to limitations in exploration and due to requirements for prolonged life support, it has become only possible to explore deep reaches of space through the use of robotic space probes. Through the efforts of NASA and ESA many robotic space probes have been launched to explore nearby asteroids' and comets. However, for these types of deep space missions, the robotic space probe is often far from Earth. This is a cause for many failures as the robotic probe is subjected to unknown conditions and the relapse time for communication may not be enough for the probe to react. Thus, many robotic space probes from various space agencies have been lost due to lack of communication with the probe. In addition, the amount of power that is required for deep space missions is also considerable. There should be enough power to supply the navigation systems, communication systems, propulsion systems as well as the internal heat systems in the probes. Moreover, due to the vast distances involved in the solar system, the power supply should be reliable enough for 25 to 40 years as this is the time that it will take for a robotic space probe to reach the heliopause. Hence, in order to fulfill these criteria, robotic space probes require advanced artificial intelligence protocols as well as advanced power systems to meet the long range, long duration mission requirements. Moreover, it is essential to design these systems in the most economical way possible, so that these missions can become plausible especially in light of the reduced budgets of the space programs all over the world. This paper discusses the possible solutions, as well as important challenges ahead for deep space robotic space probe missions.

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Missions (Including Commercial)

Dust Around the Moon: Preliminary Results from the LADEE Ultraviolet Visible Spectrometer

A main scientific objective of the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission is to directly measure the lunar exospheric dust environment and its spatial and temporal variability. Past studies have suggested that impacts could excavate material into a dust cloud surrounding the moon. Meteor showers, in particular, present a large number of concentrated impact events on the surface. The Ultraviolet and Visible Spectrometer (UVS), a CCD spectrograph which operates between 230 – 810 nm with a spectral resolution of <1 nm, is designed to make observations of the lunar exosphere and search for dust. Observations of the lunar limb using the UVS three-inch telescope include limb "stares" ranging from ~20 km above the surface at the terminators to ~40 km at around local noon time. At the terminators, the spacecraft can "nod" the telescope between the surface and about 50 km. Both "backward" looks (stares that point in the anti-velocity direction of the spacecraft), and "forward" looks (which flip the spacecraft to allow UVS to look in the ram direction) have been completed to permit observations in both back and forward scattering regimes. The spectra are taken at relatively high cadence (between 1 and 10 seconds each) during these observations and allow a temporally and spatially resolved view of the scatter in the exosphere. Convolution of these profiles with expected contributions from impact events can permit characterization of present day impacts on the moon. Over the course of the 140 day mission, UVS observed a dynamic and highly time-dependent dust and volatile environment on the Moon. In this study, we will present preliminary results of lunar limb observations from the Ultraviolet and Visible Spectrometer and star tracker images onboard LADEE and discuss new experiments and modeling of the contributions to the lunar dust exosphere.

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Missions (Including Commercial)

Introduction to elemental distribution of Si and other major elements on the lunar surface observed by Kaguya GRS

Gamma ray spectrometry (GRS) allows us to characterize the elemental composition of the upper tens centimeters of solid planetary surfaces. High energy resolution gamma ray data were firstly obtained by the Kaguya Gamma-Ray Spectrometer (KGRS). Elemental maps generated on the basis of the KGRS include natural radioactive elements (K, Th, U) as well as major elements maps (e.g., Ca and Al). The elemental maps of Si, Fe, and Ti were recently investigated. Analysis of the Si gamma ray has been investigated using the 4934 keV Si peak produced by the thermal neutron interaction 28Si(n,g)29Si, generated during the interaction of galactic cosmic rays and surface material containing Si. The emission rate of gamma rays is directly proportional to the abundance of Si from the lunar surface; however, it is also affected by the thermal neutron density in the lunar surface. For the correction associated with neutron effect on the Si gamma ray data, we used the relative variation in global distribution of thermal neutron flux measured by Lunar Prospector. Normalization of Si elemental abundance using the KGRS data was accomplished using Apollo returned sample data. The normalized Si elemental abundance of the KGRS data ranged from about 15 to 27% Si. The lowest and highest SiO2 abundance correspond to mineral groups like pyroxene group (PKT region) and feldspar group (Northern highlands), respectively. Our elemental map of Si derived from KGRS data shows that the highland areas of both nearside and farside of the Moon have higher abundance of Si, and the mare regions of the nearside of the Moon have the lowest Si abundance on the Moon. Our study clearly shows that there are a number of Si enriched areas compared to that of Apollo 16 site. This result is similar to the mineralogical data obtained by Diviner. The feldspathic highland areas are confirmed through the elemental map of Si by the KGRS data. When the Si map of KGRS data is compared with the LRO's mineralogical map, a reasonable agreement in understanding of the dichotomy between lunar mafic and feldspathic regions of the moon is confirmed. This presentation also includes a brief introduction to the preliminary results of Fe and Ti elemental maps obtained by KGRS. These two elements allow us to distinguish among lunar rocks, and Ti forms the basis for classifying the basalts that make up the lunar maria. Mare basalts erupting from the interior after formation of the lunar crust and filling large basins can retain important information in concert with petrologic relationships to infer the mantle compositions of the interior. Fe and Ti contents in mare regions are much higher than those in highlands. Especially high concentration of Ti on Mare Tranquillitatis is confirmed.

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Missions (Including Commercial)

The Space Launch System and the Path to Mars

Introduction: The Space Launch System (SLS) is the most powerful rocket ever built and provides a critical heavy-lift launch capability. Enhanced capabilities enable missions including human exploration, planetary science, astrophysics, heliophysics, planetary defense and commercial space exploration. We will focus on mission concepts relevant to the Global Exploration Roadmap (GER) and the Solar System Exploration Research Virtual Institute (SSERVI) mission.Asteroid Redirect Mission (ARM): Bill Gerstenmaier at the NASA Lunar Science Institute (NLSI) meeting in July 2013 referred to the ARM in part as a mission to the lunar vicinity. The ARM mission requirements result in system design based on a modified version of our 702 spacecraft product line. Including a NASA Docking System (NDS) on the Asteroid Redirect Vehicle allows for easier crewed exploration mission integration and execution.Asteroid Exploration Module: Crew operations at a redirected asteroid could be significantly enhanced by providing additional systems and EVA capabilities beyond those available from Orion only missions. An Asteroid Exploration Module (AEM) located with the asteroid would improve the science and technical return of the asteroid mission while also increasing Orion capability through resource provision and providing an abort location and safe haven for vehicle contingencies.Cislunar Exploration Platform: The AEM could be repurposed as a cislunar exploration platform that advances scientific research, enables lunar surface exploration and provides a deep space vehicle assembly and servicing site. The Exploration Platform provides a flexible basis for future exploration, since it reduces cost through reuse of expensive vehicles and reduces the number of launches needed to accomplish missions. International Space Station (ISS) industry partners have been working for the past several years on concepts for using ISS development methods and residual assets to support a broad range of exploration missions. These concepts have matured along with planning details for NASA's SLS and Multi-Purpose Crew Vehicle (MPCV) to allow serious consideration for a platform located in the Earth-Moon Libration (EML) system.Lunar Surface: The mission objectives are to provide lunar surface access for crew and cargo and to provide as much system reuse as possible. Subsequent missions to the surface can reuse the same lander and Lunar Transfer Vehicle.Mars Vicinity: The International space community has declared that our unified long term goal is for a human mission to Mars but major work remains to define how it will be done. Translunar infrastructure and heavy lift capability are key to this approach. Recent analysis has suggested that a habitat-based gateway in translunar space would be helpful as an assembly node for Mars and for many other missions. The moons of Mars would provide an excellent stepping stone to the surface. As a "shake-down" cruise before landing, a mission to Deimos or Phobos would test all of the systems except those needed to get to the surface and back. This test would provide confidence for the in-space transportations and crew habitat systems.

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Missions (Including Commercial)

The Lunar Mapping and Modeling Portal: Tools for Mission Planning, Science, and Outreach

The Lunar Mapping and Modeling Portal (LMMP) provides a web-based Portal and a suite of interactive visualization and analysis tools enabling mission planners, lunar scientists, and engineers to access mapped lunar data products from past and current lunar missions. While emphasizing mission planning, LMMP also addresses the lunar science community, the lunar commercial community, education and public outreach (E/PO), and anyone else interested in accessing or utilizing lunar data. Its visualization and analysis tools allow users to perform analysis such as lighting and local hazard assessments including slope, surface roughness and crater/boulder distribution. Originally designed as a mission planning tool for the Constellation Program, LMMP has grown into a generalized suite of tools facilitating a wide range of activities including the planning, design, development, test and operations associated with lunar sortie missions; robotic (and potentially crewed) operations on the surface; planning tasks in the areas of landing site evaluation and selection; design and placement of landers and other stationary assets; design of rovers and other mobile assets; developing terrain-relative navigation (TRN) capabilities; deorbit/impact site visualization; and assessment and planning of science traverses. Significant advantages are afforded by LMMP's features facilitating collaboration among members of distributed teams (e.g., mission planning team, mission proposal team). Team members can share visualizations and add new data to be shared either with the entire LMMP community or only with members of their own team. Sharing of multi-layered visualizations is made easy with the ability to create and distribute LMMP's digital bookmarks. LMMP fosters outreach, education, and exploration of the Moon by educators, students, amateur astronomers, and the general public. These efforts are enhanced by Moon Tours, LMMP's mobile application, which makes LMMP's information accessible to people of all ages, putting opportunities for real lunar exploration in the palms of their hands. Moon Tours allows users to browse and search LMMP's entire catalog of over 600 data imagery products ranging from global basemaps to LRO's Narrow Angle Camera (NAC) images providing details of down to .5 meters/pixel. Users are able to view map metadata (e.g., abstract of the data) and can zoom in and out of the map to view more or less data, as well as pan around the entire lunar surface with the appropriate basemap. They can arbitrarily stack the maps and images on top of each other, showing layered views of the surface with layer transparency adjusted to suit the user's desired look. They can even view lunar terrain data rendered in realtime 3D, and calculate distances between locations on the lunar surface. While great utility is provided by LMMP's interface and tools, it also provides particular value through its ability to serve data to a variety of other applications. In the outreach realm, this has been demonstrated with data served to planetariums and NASA's Eyes on the Solar System. This presentation will provide an overview of LMMP Uses and capabilities, highlight new features, and preview coming enhancements. It will supplement and enhance the LMMP demonstration that will be hosted at the Forum..

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Missions (Including Commercial)

Fifty Years of Exploration Science with the Deep Space Network

Established on 1963 December 24, the Deep Space Network (DSN) has played an integral role in science and exploration from the beginnings of the space program. Receiving the data from the robotic Ranger spacecraft, the DSN helped provide the first high resolution images of the surface of the Moon, the first human exploration target. During the Apollo program, the DSN downlinked both a wealth of scientific data and provided the critial communications with the astronauts. Later, the Goldstone radar observations helped provide early indications of water in the lunar polar regions, an observation subsequently confirmed by the LCROSS mission.Today, the DSN continues the tradition of providing science measurements and advanced reconnaissance for robotic and human missions. Radio science links between spacecraft and the DSN are used to probe the atmospheres, gravity fields, and interior structures of bodies, and the Goldstone radar system is used to measure the rotation rates, sizes, shapes, surface features, and precision orbits for asteroids. Highlights of the precision of radio science measurements include recent results from Mars Express-DSN links and the GRAIL mission. During recent Mars Express close fly-bys of Phobos, radio science measurements on the Mars Express-DSN link indicate that the interior of Phobos is highly porous and suggesting that this Martian satellite re-accreted in place. The GRAIL mission used both spacecraft-spacecraft and spacecraft-DSN links to provide an unparalled gravity field and near sub-surface structure map of the Moon. Highlights of Goldstone radar observations include the asteroid (101955) Bennu, which is the target of the forthcoming OSIRIS-REx mission, and imaging and precision orbit determination of the close-approaching asteroids 99942 Apophis and 2012 DA14.Looking toward the future, the existing suite of science measurement techniques both will continue and is likely to expand with higher resolution radar imaging and the inclusion of laser communications. In addition to even higher precision link science to spacecraft for probing interior structures, the laser communication infrastructure is likely to allow ``opportunistic” use of laser ranging to the Moon and other bodies in the inner solar system.Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics & Space Administration.

Author: PASCAL LEE

POSTER

Missions (Including Commercial)

Phobos And Deimos & Mars Environment (PADME): A Proposed Discovery Mission

Ever the since their discovery in 1877 by American astronomer Asaph Hall, the two moons of Mars, Phobos and Deimos, have been mysteries. Spacecraft missions have revealed that they are irregular-shaped small bodies with a long collisional history and complex geology, but their origin remains unknown. Three very different hypotheses have been proposed for their origin: 1) They are captured asteroids, possibly primitive D-type asteroids from the outer part of the main asteroid belt; 2) They are remnants of Mars's own formation; 3) They are reaccreted impact ejecta from Mars. Superimposed on these hypotheses is another unresolved hypothesis: 4) Phobos and Deimos were once part of a single larger object. There are also two intriguing hypotheses concerning the present evolution of Phobos and Deimos: 5) A faint dust cloud fed by micrometeoroid impacts exists in steady-state in the immediate vicinity of Phobos and Deimos; 6) A faint dust ring and a faint dust torus occur at the location of Phobos and Deimos's orbits, respectively. Each one of these hypotheses has radically different implications regarding the evolution of the solar system, and/or the origin and evolution of its planets, satellites, and/or rings. These hypotheses are best tested or at least constrained by simultaneously investigating the internal structure and bulk composition of Phobos and Deimos, and the abundance and distribution of dust in their vicinity. The Phobos And Deimos & Mars Environment (PADME) mission is a proposed new NASA Discovery mission that would test the above hypotheses by investigating simultaneously the internal structure and bulk composition of Phobos and Deimos, and the abundance and distribution of dust in Mars orbit. The PADME mission would use the proven LADEE spacecraft bus, radio science, and a suite of highly mature instruments to achieve its science objectives. PADME would launch in 2020 and reach Mars orbit in early 2021. It would then begin a series of slow and increasingly close flybys of Phobos to carry out the following baseline observations in unprecedented detail: a) measure the small body's gravity field, b) image its position, orientation, shape, and surface features; c) measure the bulk composition of the regolith; d) measure the abundance and distribution of dust in its vicinity. The same series of observations would then be performed at Deimos. PADME would offer a low-cost and low risk giant leap in our knowledge about the evolution of the solar system and the origin and evolution of small bodies, of small planetary satellites, of planetary rings, and of Phobos and Deimos specifically. PADME would also fill key strategic knowledge gaps identified by NASA's HEOMD in advance of planning human missions to Phobos and/or Deimos. PADME would be built, managed, and operated by NASA Ames Research Center. Partners include the SETI Institute, NASA JPL, NASA KSC, University of Colorado, University of Maryland, Cornell University, Royal Observatory of Belgium, JAXA, and others.

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ORAL

Missions (Including Commercial)

Atromos: A Cubesat-Derived Mission for the Exploration of the Martian System Using M-PODs

A companion mission is proposed that could provide an enhanced capability of exploring scientifically provocative sites on the surface of Mars and related moons. Options are discussed for a 'companion' mission which could be deployed from the cruise-stage of larger dedicated Mars missions. While the precedence is the DS-2 mission attempted in 1998, the intent would be to 'soft' land payloads on the surface of the planet or moons. In the same fashion that the compartmentalization of the risk is now routinely done for Low Earth Orbit (LEO) satellites, an M-POD (Mars PicoSat Orbital Deployer) is proposed at a larger scale that would have an analogous function. For the planetary surface area targets, an Entry/Descent/Landing (EDL) technology is uniquely described that permits the deployment of such missions from the M-POD. For Phobos, a propulsion system is similarly described. Given the current interest in interplanetary nano-satellites, the Mars system is particularly attractive in part due to the COM infrastructure that already exists – and thus makes such an undertaking credible. This 'companion' mission capability is shown to dramatically enhance the scientific benefit at low cost and risk.

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Missions (Including Commercial)

MERLIN: A Science and Exploration Mission to the Moons of Mars

Mars' moons Phobos and Deimos are low-albedo, D-type bodies. Their compositions have been interpreted as highly space-weathered material like that forming bulk Mars or Mars's crust, or alternatively primitive carbonaceous material, possibly sampling material that contributed organics and volatiles to the accreting terrestrial planets. The moons' origins, as well as their potential for in situ resources for future explorers, depend on their composition. A composition related to that of Mars would indicate an origin within the Mars system, yet offer minimal C and H for future explorers; a primitive carbonaceous composition would imply formation in more distant parts of the solar system, possibly related to Trojan asteroids, any may provide significant in situ resources. A Discovery-class mission concept, the Mars-Moon Exploration, Reconnaissance and Landed Investigation (MERLIN), will use in situ compositional measurements to test models for the moon's origin [1]. The nominal landing target is Phobos. The scientific measurement objectives of MERLIN are to determine Phobos' elemental and mineralogical composition, to investigate its volatile and organic content, to characterize processes that have modified its surface, and to determine how it is related to Deimos and other solar system bodies. These same measurements characterize physical properties of the surface and the moon's environment, providing valuable precursor information preparatory to future human exploration. To achieve MERLIN's objectives, a landed payload will obtain stereo imaging and measurements of elemental and mineralogical composition and interior structure. An orbital payload will acquire global high-resolution and color imaging, putting the landing site in context, and characterize the radiation and particle environments near both moons. Following MOI the spacecraft spends several months in elliptical orbits to characterize the moons' "dust belts" and performs multiple close flybys of Deimos to acquire near-global imaging and a refined density estimate. It then performs a rendezvous with Phobos, using small changes in the spacecraft's orbit around Mars to investigate Phobos from a range of altitudes and illuminations. Data taken during 1- to 2- km altitude flyovers will certify a landing site. The spacecraft will be delivered to a point several km above the surface, and will navigate to landing on one of Phobos' two distinct spectral units. A 90-day baseline landed operations period will provide a complete set of landed measurements. A science enhancement option includes ascent and relanding to perform in situ study of the second distinct spectral unit.References: [1] Murchie, S. et al. (2012) MERLIN: Mars-Moon Exploration, Reconnaissance and Landed Investigation, Global Conference on Space Exploration, paper GLEX-2012.03.2.1x12281, Washington, D.C., May 2012.

Author: CHARLES RADLEY

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Missions (Including Commercial)

CTIPS - (CisLunar Tether Deployment, Physics and Survivability)

Very long tethers in space (thousands of kilometers) offer interesting and useful applications. However, to date no tethers approaching this length have been attempted in space. There are numerous questions about how such tethers could be deployed and how they might behave during and after deployment.Tether deployment near Earth is subject to high tidal forces, which become especially significant with longer tethers. Furthermore, unless the orbit is perfectly circular, tidal forces will vary greatly. This introduces non-deterministic disturbances into the system, which complicate the design and could result in unstable systems. Therefore, prior to attempting long tether deployments near Earth it is beneficial to perform such tests at some distance away from Earth in a stable environment with low, non-varying tidal forces.One of the more convenient types of locations near to Earth which have low and nearly constant tidal forces is the Earth-Moon Lagrange 1 Point. (EML1) LiftPort Group proposes a mission concept called CTIPS - (CisLunar Tether Deployment, Physics and Survivability) experiment to investigate behavior of long tethers during and after deployment, at EML1. This testing is essential for developing technology to deploy planetary and lunar elevators, as well as long tethers for other applications.

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Missions (Including Commercial)

From ODEs to PDEs : Simulating and Managing the Behavior of Lunar Space Elevators

A Lunar Space Elevator (LSE) would be by many orders of magnitude the largest structures ever built and deployed by our civilization, with an expected tether length of well over 250,000 km. Even preliminary tethers deployed in CisLunar space, either for engineering tests or for Lunar sample return or for other scientific purposes, would likely exceed the diameter of the Earth in length and thus be the biggest mechanical structures ever created. Such “CisLunar” tethers will present novel problems of simulation, monitoring and control. Unlike conventional problems in orbital dynamics, which can be described by Ordinary Differential Equations (ODEs), the dynamics of CisLunar tethers will requiring modeling by Partial Differential Equations (ODEs). Mathematically the modeling of CisLunar tethers will have similarities to both Numerical Weather Forecasting (NWF) and the numerical modeling of large structures, such as bridges. CisLunar tethers will support a variety of oscillations and normal modes, excited by both gravitational perturbations and the motion of cargo vehicles along the tether, that are unlikely to be fully observed by any monitoring system; the techniques developed for NWF data assimilation are thus likely to be essential for the high capacity usage of an operational LSE. This presentation will describe the mathematical basis for CisLunar tether monitoring and operations and the current status of tether simulations.

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Author: CHARLES RADLEY

ORAL

Missions (Including Commercial)

Lunar Elevator - Partial Deployment during Translunar cruise

It is rather difficult to deploy a lunar elevator initially from the Earth-moon L1 Lagrange location because the tidal forces are very small. So the two ends of the tether could drift in quasi-random fashion and become uncontrollable and tangled. They will need to reach a length of several thousands kilometers before they become gravity gradient stabilized. The question of how to achieve such a deployment in the absence of tidal forces is difficult.So we consider deployment of a few thousand kilometers before reaching the L1 location.The partial deployment could begin shortly after the Trans-lunar Injection burn. Two options for initial deployment are: 1) Springs and/or small rockets can be used to fire out the two ends of the tether, this will impart initial separation velocity 2) spin up the spacecraft and then release the ends of the tether and deployment begins via centrifugal force. Over a few days the three objects (hub and two tether ends) will tend to drift apart since they are in different orbits, and this will introduce useful tension on the tether. This quasi-tidal force will maintain tension during the cruise. We plan to use electric propulsion which will slowly raise the perigee until the tether craft rendezvous at EML1. As for electric propulsion, it is probably not necessary to have electric thrusters on all three objects, perhaps only on the central object, and the two others will remain attached via the tethers During this time the tidal tension will reduce. Prior to this, it might make sense to spin up the system, maybe to one or two revs per hour, to keep it under controlled attitude and tension. Once at EML1, the system will be de-spun and the tether aligned on the Earth-Moon axis and achieve gravity gradient stabilization. Then it can be deployed to its full length.

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Missions (Including Commercial)

Commercial Mining with a Lunar Elevator

The Earth's Moon is a treasure trove of mineral resources, such as precious metals, rare earth elements, Helium-3 and Oxygen for propellants. However, the cost of soft landing on the Moon is currently very high. Using modern fibers we can build a lunar elevator which reduces the cost of lunar landing sixfold.The lunar elevator concept is a long tether which is loaded under tension by terrestrial and lunar gravity. One end is anchored on the Moon and the other end free, hanging towards Earth. The orbital center of mass of the system is located at Earth-Moon Lagrange one location (EML1) approximately 50,000 kilometers from the lunar surface. The near-side L1 tether is attached to the lunar equator at Sinus Medii. Such a tether can now be built inexpensively from commercially available materials.For a one time capital cost of US$800Million [2012], a lunar elevator can be built today using existing available materials. This first generation lunar elevator will softly deliver an infinite number of payloads to the lunar surface, each weighing 100 kg, and retrieve the same amount of material from the lunar surface. The alternative of using chemical rockets to soft land on the Moon [or return material] is prohibitively expensive. The lunar elevator eliminates the delta-vee advantage of near Earth asteroids. Everything you find in asteroids is available in lunar regolith at somewhat lower concentrations.Helium-3 today sells for a million dollars per ounce on the secondary market, demand far exceeds supply. It is abundant on the Moon but rare on Earth. US supplies are rationed by the White House and will be exhausted by 2030. Lunar rocks [meteorites] today sell for about $200,000 per kg.Rare Earth Elements (REEs) are vital to defense and high technology industries, today 96% of REEs come from China-controlled assets. There are few alternative mining sites, but the Moon is one.Use of lunar oxygen would reduce the cost of geosynchronous spacecraft launch by about 7 times.A lunar elevator can return lunar material to Earth or LEO at a low enough cost that prices of certain commodities will generate sufficient revenues to amortize the capital cost over reasonable period of time.and then operate the system at a net profit. The lunar elevator could reduce the cost of lunar mining of such commodities to a par with terrestrial mining.

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Ceres soft landing and sample return using synchronous tether elevator

The dwarf planet Ceres is a high priority target for exploration due to recent confirmation of escaping water plumes. A substantial percentage of the body is now believed to be composed of water. Ceres has a mass about 1/10th of Earth's Moon and rotates about every nine hours. The altitude of a synchronous circular orbit about Ceres is therefore at an altitude of about a few thousand kilometers above Ceres' equator. A tether or space elevator centered by mass on that altitude can be inexpensively constructed from one of a variety of commercially available polymer materials. It would extend in two directions from the synchronous orbit; firstly downwards to the surface of Ceres, and secondly upwards away from the synchronous orbit to a counterweight.The surface end need not be attached to the body, and indeed the elevator COM altitude could be slightly below the synchronous altitude, so the system would tend to slowly drift around the equator of Ceres. This system can thus cruise around the Ceres equator, and collect samples from the entire circumference. It can also soft-land multiple sensors and rovers around the equatorial band of Ceres. The synchronous tether cannot access the higher latitudes, but that might be possible by a rotating tether in a polar orbit, which would transfers samples (or equipment) between the equator and the higher latitudes. However the rotation rate of Ceres is high enough that a polar orbiting tether might have difficulty to rendezvous with objects on the surface due to the transverse motion of the surface relative to the tether tip. To soft land payloads from the polar tether would also require cancellation of the transverse surface velocity component.It is possible that a polar orbit around Ceres would be disturbed by its non-uniform gravitational field, and by Jupiter and the Sun. Therefore, station-keeping is probably required, and this could be done efficiently with a solar-powered electric thruster. It might therefore be attractive to maintain the spacecraft in an orbit which is orthogonal to the Sun so it is in continuous sunlight, and the solar arrays constantly illuminated. This type of orbit is known as a dawn-dusk orbit.

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A Roadmap for the Development of the Lunar Space Elevator

A Lunar Space Elevator (LSE) could be constructed with existing materials, considerably accelerating the exploration and economic development of the solar system. The LSE would be an extremely long tether extending from the Lunar Surface, through the Earth-Moon L1 Lagrange point (EML 1) and into CisLunar space. Requiring a relatively modest capital investment, as compared to chemical rockets, the LSE will reduce the cost of lunar soft landing sixfold and cost of lunar sample return is by about one thousand times. For soft landing the LSE would thus pay for itself in 20 payload cycles; for sample return - in a single payload cycle. The LiftPort Group Lunar Space Elevator Development plan includes an initial tether test in CisLunar space, CTIPS (CisLunar Tether Deployment, Physics and Survivability), followed by a rotating tether Lunar sample return mission or missions, ROTSAR (ROtating Tether SAmple Return) and the Lunar Space Elevator Infrastructure (LSEI). The LSEI prototype, requiring launch of a single heavy lift vehicle, would be able to return roughly 1 ton of lunar samples per year, and deploy a similar quantity of equipment onto the Lunar surface. This presentation will describe the various components of LiftPort's Development plan, how it will lead to an operational LSEI, and its implications for the economic development of the Moon.

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Missions (Including Commercial)

CTIPS - (CisLunar Tether Deployment, Physics and Survivability)

Very long tethers in space (thousands of kilometres) offer some interesting and useful applications. However, to date no tethers approaching this length have been attempted in space. There are numerous questions about how such tethers could be deployed and how they might behave during and after deployment.Tether deployment near Earth is subject to high tidal forces, which become especially significant with longer tethers. Furthermore, unless the orbit is perfectly circular tidal forces will vary greatly, which will introduce non-deterministic disturbances into the system, which complicate the design and could result in unstable systems. Therefore, prior to attempting long tether deployments near Earth it could be beneficial to perform such tests at some distance away from Earth in a stable environment with low non-varying tidal forces.One of the more convenient types of locations near to Earth which have low and nearly constant tidal forces are the Earth-Moon lagrange locations. (EMLs) LiftPort Group proposes a mission concept called CTIPS - (CisLunar Tether Deployment, Physics and Survivability) experiment to investigate behavior of long tethers during and after deployment, at an EML location. This testing will be essential for developing technology to deploy planetary and lunar elevators, as well as long tethers for other applications.

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It is rather difficult to deploy a lunar elevator initially from the Earth-moon L1 Lagrange location because the tidal forces are very small. So the two ends of the tether could drift in quasi-random fashion and become uncontrollable and even tangled they will need to reach a length of several thousands kilometres before they become gravity gradient stabilized, and the question how to achieve such a deployment in the absence of tidal forces is difficult..So we consider deployment by a few thousand kilometers before reaching the L1 location.The partial deployment could begin shortly after the Trans-lunar Injection burn. Two options for initial deployment are: 1) Springs and/or small rockets can be used to fire out the two ends of the tether, this will impart initial separation velocity 2) spin up the spacecraft then release the ends of the tether and deployment begins via centrifugal force. Over a few days the three objects (hub and two tether ends) will tend to drift apart since they are in different orbits, and this will introduce useful tension on the tether. This quasi-tidal force will maintain tension during the cruise. We plan to use electric propulsion which will slowly raise the perigee until the tether craft rendezvous at EML1/2. As for electric propulsion, it is probably not necessary to have electric thrusters n all three objects, perhaps only on the central object, and the two others will remain attached via the tethers During this time the tidal tension will reduce. Prior to this, it might make sense to spin up the system, maybe to one or two revs per hour, to keep it under controlled attitude and tension. Once at EML1/2 the system will be de-spun and the tether aligned on the Earth-Moon axis and achieve gravity gradient stabilization. Then it can be deployed to its full length.

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Missions (Including Commercial)

Rotating tethers in lunar polar orbit for sample return

Rotating tether Lunar sample return mission or missions, ROTSAR (ROtating Tether SAmple Return)A lunar orbiting tether with weights at each end rotates such that the tether is always in the orbital plane, and the axis of its rotation is orthogonal to the orbital plane.The speed of the tether tip equals the orbital speed, the lower tip velocity vector is opposed to the orbital velocity vector, so it is like a wheel rolling along the lunar surface, i.e. the speed of the tether tip, when at the lunar surface, will be near zero relative to the Earth-Moon inertial frame . For a tether in polar orbit around the Moon, the rotation of the Moon about its axis is slow [~= 17 cm/s] so would not introduce significant transverse forces on the tether tip at the lunar surface. Since lunar rotation is the largest residual relative motion [between the tether tip and the lunar surface] it is practical for the tether tip to rendezvous with and attach to objects on the lunar surface. It is also practical for the tether to release payloads which soft land on the lunar surface with small and acceptable horizontal velocity.Payloads can be soft landed on (or collected from) different latitudes on the lunar surface. In particular we would use the equatorial zero longitude and the antipodal 180 degrees lunar longitude points as depot sites, since they can be accessed by a stationary lunar elevator, for further transport to/from Earth or cislunar trajectories.Polar lunar orbits are significantly disturbed by the Earth's gravity, therefore frequent station-keeping burns will be needed to extend the life of the system beyond a few months. Electric propulsion would be an efficient option. The orbit could be maintained in a plane orthogonal to the Sun so it is in continuous sunlight, maximizing solar energy to power the electric thruster. This is known as a dawn-dusk orbit type.Over the course of a lunar sidereal month a polar orbiting ROTSAR would overfly the entire range of lunar longitudes. Depending on the phasing of the spacecraft around the lunar orbit, it could access any point on the lunar surface. For a typical orbital period of 3 hours, there would be approximately 120 orbits per month. The distance between each successive swath of each orbital pass at the lunar equator would be about 100 kilometres depending on the precise orbital period. To increase the frequency with which each point on the lunar surface could be accessed, multiple ROTSARs could be deployed, separated from each other around the polar sun-synchronous [dawn-dusk] orbit. A ROTSAR acting in conjunction with a stationary lunar elevator can establish a two-way supply chain between the Earth and any point on the lunar surface, accommodating delicate payloads, e.g humans. It can also collect samples from any point on the lunar surface, and deposit them near the base of the lunar elevator for return to Earth.

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Missions (Including Commercial)

Lunar Elevator - Payload transfer on Earthbound flow

The weight of the heat shield for Earth atmosphere entry is rather heavy, but such hardware is needed for lunar sample return. However, it is inefficient and expensive to soft land this equipment on to the lunar surface. It would be more efficient to store the heat shield at the Earth-Moon L1 lagrange location.This can be done in conjunction with a lunar elevator tether system. Samples from the lunar surface are collected via a lunar elevator. The tether climber leaves the lunar surface and moves earthwards reaching a cruise speed of about 700 m/sc. In order to maintain maximum payload throughput over time we need to maintain the velocity and not slow down. The climber needs to rendezvous and connect with the heat shield with a smaller closing velocity to avoid damage or destruction. Hence we must start the heat shield moving earthwards at a few hundred metres per second, with a small enough velocity that the climber can catch up with it in a reasonable time, but large enough to avoid destructive impact.We will need to analyze various velocity profile of the heat shield module, and the starting time of the acceleration.The collision between the climber and the heat shield is softened by shock absorbers and the payload is then connected to the heat shield by latches. The climber then separates from the payload and decelerates to a stop. The heat shield with payload are released from the tether and fall ballistically to Earth where they enter the atmosphere and are recovered.The climber returns to the EML1 location (or other point along the tether) where it is loaded with a new payload which it then transports to the lunar surface.This cycle is then repeated an arbitrary number of times.

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Missions (Including Commercial)

Mars landing and sample return using Phobos based elevator

We analyze how much delta-vee saving we can gain for Mars landing and Mars surface launch using Phobos elevator.The lower end [tip] of the Phobos elevator hangs in Mars' atmosphere moving at ~500 metres per second, this is much less than orbital velocity at that altitude. For an object sitting on the Mars surface, a small sub-orbital burn will allow the Mars lander to take-off and rendezvous with the tip of the Phobos tether. A cheaper method is for an aircraft to take off from a runway and fly up to the tether end point and rendezvous at a reasonable altitude within the aircraft operational ceiling. The tether tip can potentially also touch the Mars surface from time to time according to a profile taking advantage of the eccentricity of Phobos orbit and the topography of the martian terrain.For a single mission, the delta-vee to reach Phobos with a tether will be rather high. However, we must calculate the savings in cost for Mars take-off and landing, and then clculate how many Mars lander missions would result in a delta-vee saving wich exceeds the delta-vee cost of establishing the tether on Phobos.Drag Force = 1/2 rho v^2 C_D Av = 533 m / sec. The speed of sound on Mars (surface std atmosphere, 6 millibars pressure) is 244 m/sec, so this is Mach 2.2rho_surface = 0.02 kg / m^3let us assume a 20 ton body with a projected radius = 1 meter, so that A = pi meter^2From looking at various tables (include R.H. Goddards) C_D ~ 0.3 is reasonable for a "well designed" body at mach 2.2Drag = 2700 Newtons (and power dissipated = 1.4 MW)Gravity force on this body = 73000 NewtonsDrag / Gravity ~ 4%So we can "fly" this inside of Mars's atmosphere. Now, note that the Phobos orbit eccentricity e = 0.0151 and a = 9378 km, so ae (the deviation from the mean) is 141 km. So, the tip could be at 141 km average altitude and dip down to the surface once per orbit, and up to 282 km once per orbit, BUT, Pavonis Mons is on the equator, and it has an elevation of 14 km, so it has to be taken into account. Let us consider the rotation of Mars and the orbit of Phobos. Let a "day" be a std solar day, of 86,400 TAI seconds, and let all times be as seen from the Earth3 sidereal orbits of Phobos are 0.95673 days, or 0.932527 Mars sidereal days. 13 sidereal orbits of Phobos are 4.14583 days, or 4.04095 Mars sidereal days, which is a much better quasi-resonance. Once every 4 days the active end of the tether would become aerodynamically active and "fly" to the pickup / dropoff point (whether that is on Pavonis Mons or just on the Tharsis ridge).

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Missions (Including Commercial)

Minimalist lunar Helium-3 mining machine

There is considerable commercial potential for Helium-3 mining on the Moon.   No one has built a working nuclear fusion reactor, yet there is much discussion of lunar Helium-3 (3He) isotope as nuclear fuel. Alas, the fusion market simply does not exist – and will not in a predictable timeframe. The fusion discussion has distracted the community from the market which already exists for 3He; a market which can be profitably supplied from the Moon more cheaply than from terrestrial sources. Surprisingly, since 2001 a strong new market has rapidly emerged. 3He is in great demand since the 9/11 attacks. New demand has been driven by the US Department of Homeland Security, which needs 3He for neutron detectors at all seaports, airports and borders, to scan for nuclear material. Demand also increased from the medical sector (MRIs), and for natural gas exploration. There is increasing demand from the oil and gas exploration sector from wireline well logging companies, and they currently receive top priority by the White House allocation committee. The US 3He stockpile came from the decay of nuclear warheads; it is dwindling rapidly. In 2008 the White House imposed 3He rationing to eke out remaining reserves and supply fell from 80,000 to 14,000 liters per year. Projected demand for 3He implies that U.S. production alone cannot meet anticipated worldwide demand..   Global demand is now over 60,000 liters per year, and the price shot up from $100/l in 2008 to $2,000/l in 2009. The price continues to increase.. Current White House projections are that national He3 supplies will be completely depleted some time between 2025 and 2035. Supplies from Russia and Canada will not meet global demand.LiftPort is planning a proof of concept of a minimalist lunar helium-3 mining robot, approx 100 kg, based on the designs of the University of Wisconsin Fusion Technology Institute.There will be opportunities for NASA science instruments to fly on LiftPort provided infrastructure to the lunar surface. As a by-product of Helium-3 mining, a large quantity of many other volatile gases will be produced all of which will be of benefit to NASA operations in the lunar vicinity, such as: water, carbon monoxide, carbon dioxide, and methane. These gases can be used for rocket propellant and to feed fuel cells to produce energy during the lunar night.The Helium-3 mining machine would be an apparatus mounted on a rover machine bus developed by one of the Google Lunar Xprize teams, there are several to choose from.   The machine will be delivered to cislunar space via the NASA SLS.   and will soft land on the lunar surface. The system will be solar powered and will heat the regolith to liberate volatile gases.   Fractional distillation will separate the Helium from the other constituent gases; then a superleak isotope enrichment process will separate the Helium-3 from the Helium-4.

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SSERVI-ESF14-197

Author: DENNIS WINGO

POSTER

Missions (Including Commercial)

ISEE-3 Reboot Project

The ISEE-3 Reboot Project was announced in Mid-April 2014. Our plan was simple: we intended to contact the ISEE-3 (International Sun-Earth Explorer) spacecraft, command it to fire its engines and enter an orbit near Earth, and then resume its original mission - a mission it began in 1978. Working in collaboration with NASA assembled a team of engineers, programmers, and scientists and made plans to utilize several large radio telescope to contact ISEE-3. The ultimate aim of the ISEE-3 Reboot Project was to facilitate the sharing and interpretation of all of the new data ISEE-3 sends back via crowd sourcing. NASA told us officially that there was no funding available to support an ISEE-3 effort - nor was this work a formal priority for the agency in the current budget environment. But NASA also said that any data that ISEE-3 might generate would have real value and that a crowd funded effort such as ours had real value as an education and public outreach activity. This activity was led by the same team that has successfully accomplished the Lunar Orbiter Image Recovery Project (LOIRP): SkyCorp and SpaceRef Interactive. Education and public outreach was to be coordinated by the newly-formed non-profit organization Space College Foundation. Our software team recreated lost hardware and software using “software radio”. We also amassed a collection of original program documentation. Our trajectory efforts were coordinated by experts associated with the ISEE-3 and LADEE missions. We will discuss the progress that the project has made to date and it implications for other collaborations NASA way wish to consider in the years ahead.

Author: DENNIS WINGO

POSTER

Missions (Including Commercial)

Lunar Orbiter Image Recovery Project

The Lunar Orbiter Image Recovery Project (LOIRP) was founded in 2007 to recover Lunar Orbiter mission imagery from original analog data tapes recorded as the images first arrived on Earth between 1966-1967. Funded with a mix of private and NASA money, we were able to rebuild original 50 year old FR-900 tape drives, build a modern version of the original demodulator, and recover imagery at previously unachieved resolution and dynamic range. We recovered our first image in November 2008, e enow-iconic "Earthrise" image taken by Lunar Orbiter 1 in August 1966. We completed to initial data recovery of all images from the 5 Lunar Orbiter missions in April 2014. All recovered imagery is currently being prepared for submittal to the NASA Planetary Data System. We will discuss the origin of the project, the technical and organizational challenges we encountered, the processes whereby we retrieve and archive our data, and how our imagery has been used since its recovery. We will also discuss the implications for other collaborations NASA way wish to consider in the years ahead.

Author: MARK ROBINSON

ORAL

Missions (Including Commercial)

Arne - Exploring the Mare Tranquillitatis Pit

Lunar mare “pits” are key science and exploration targets. The first three pits were discovered within Selene obser-vations [1,2] and were proposed to represent collapses into lava tubes. Subsequent LROC images revealed 5 new mare pits and showed that the Mare Tranquillitatis pit (MTP; 8.335°N, 33.222°E) opens into a sublunarean void at least 20-meters in extent [3,4]. Additionally more than 200 pits were discovered in impact melt deposits [4]. A key remaining task is determining pit subsurface extents, and thus fully understanding their exploration and scientific value. We propose a simple and cost effective reconnaissance of the MTP using a small lander (<130 kg) named Arne that carries three flying microbots (or pit-bots) each with mass of 3 kg [5,6,7]. Key measurement objectives include decimeter scale characterization of the structure of wall materials, 5-cm scale imaging of the eastern floor, determination of the extent of sublunarean void(s), and measurement of the magnetic and thermal environment. Arne will make a noontime descent and optically lock onto the MTP rim and floor shadow, 100 meters above the surrounding mare Arne will descend vertically (~1 m/s). At the top of the pit Arne will determine the position of boulders on the floor known from LROC images [3], and then maneuver to a relatively smooth spot in view of the Earth.After initial surface systems check Arne will transmit full resolution descent and surface images. Within two hours the first pit-bot will launch and fly into the eastern void. Depending on results from the first pit-bot the second and third will launch and perform follow-up observations (continue exploring same void or head west, north, and/or south). The primary mission is expected to last 48-hours, before the Sun sets on the lander there should be enough time to execute ten flights with each pit-bot.Arne will carry a magnetometer, thermometer, 2 high resolution cameras, and 6 wide angle cameras. The pit-bots are 30-cm diameter spherical flying robots [5,6,7]. Lithium hydride [5,6] and water/hydrogen peroxide power three micro-thrusters and achieve a specific impulse of up to 400 s. The same fuel and oxidizer is used for a fuel cell (en-ergy density of 2,000 Wh/kg) [5,6]. Each pit-bot can fly for 2 min at 2 m/s for more than 100 cycles; recharge time between cycles is 20 min. The pit-bots are equipped with a flash camera, magnetometer, thermometer and obstacle avoidance infrared sensors. [1] Haruyama et al. (2010) 41st LPSC, #1285. [2] Haruyama et al. (2010) GRL, 36, dx.doi.org/ 10.1029/2009GL0406355. [3] Robinson et al (2012) PSS, 69, dx.doi.org/ 10.1016/j. pss.2012.05.008 [4] Wagner and Robinson (2014) Icarus, in press. [5] Thangavelautham et al. (2012) IEEE ICRA [6] Strawser et al. (2014) J. Hydrogen Energy. [7] Dubowsky et al. (2007) Proc. CLAWAR.

Author: KATHERINE SHIRLEY

POSTER

Missions (Including Commercial)

Photometric Correction of the Diviner Thermal Channels

The Diviner Lunar Radiometer Experiment on board the Lunar Reconnaissance Orbiter is currently mapping multispectral thermal emission from the lunar surface [1]. Lunar surface composition is derived from the three narrow channels (channels 3-5) centered near 8 μm that determine the location of the Christiansen Feature (CF), which changes position as a function of silicate composition [2,3]. Diviner also maps the lunar surface at longer thermal wavelengths (12.5-400 μm; channels 6-9) that have not generally been used in mineralogical analyses. We have found that emissivity of the thermal channels varies as a function of solar incidence angle, generally giving lower emissivity values at higher incidence angles. A correction has been developed for the 8 μm channels which normalizes all Diviner daytime data to 0° incidence angles at the equator [4]; however, a correction for the thermal channels has yet to be developed. Here we describe our simple “bootstrap” approach to photometrically correct these channels.Methods: Our correction assumes that the data measured at an incidence angle of 0° is ideal. Thus, we first examine relatively homogenous locations on the Moon determined using a global map of CF values [e.g. 3], and obtain an average emissivity measurement for each. Because we assume that 0° incidence measurements are correct, the slopes between channels at this incidence angle are also taken to be true. These slopes are then projected onto the previously corrected emissivity measurements starting at channel 5 to predict values at channel 6, and so on for higher incidence angle measurements.Slopes from emissivity data from two locations (one mare, one highlands) were used to create two versions of a correction, which was then applied globally and tested at several locations in both mare and highlands areas (basaltic or felsic, respectively) and at varying coordinates.Results: We found that this type of correction improves the data measured at higher incidence angle. It does tend to overcorrect if applied to a location of different composition than the correction location used (i.e. a mare correction should be applied to only mare region). Conclusions/Future Work: This simple correction is working well in normalizing higher solar incidence angle emissivity to that obtained at a 0° incidence angle. Next, we will combine the current corrections to apply compositionally specific corrections which should fix the observed overcorrections. Eventually, another version of the correction will use the emissivity data per pixel at 0° incidence to correct the high incidence angle data. The thermal channels can then be used to give more detailed insight into surface mineralogy by increasing the amount of compositionally useful channels from 3 to 7. This could allow us to create mineral spectral indices and use spectral unmixing models.

Author: J.R. SKOK

ORAL

Missions (Including Commercial)

Mojave Volatiles Prospector – Water in the Mojave Desert as an Analog to the Lunar Poles

The Mojave Volatiles Prospector (MVP) project is a science-driven field program with the goal to produce critical knowledge for conducting robotic exploration of the Moon. MVP will feed science, payload, and operational lessons learned to the development of a real-time, short-duration lunar polar volatiles prospecting mission. MVP will achieve this through a simulated lunar rover mission to investigate the composition and distribution of surface bound and sub-surface volatiles in a natural and a priori unknown environment, improving our understanding of how to find, characterize, and access volatiles on the Moon.The science of MVP is driven by the possibility that water ice deposits exist in permanently shaded regions (PSRs) near both lunar poles (Watson et al. 1961; Arnold 1979). The floors of such craters should be extremely cold (<100K) (Vasavada et al. 1999). LRO Diviner has measured some PSRs colder than 40K. The Lunar Crater Observation and Sensing Satellite (LCROSS) mission measured ~5 wt% water in Cabeus crater (Colaprete et al. 2010). However, the distribution of water and other volatiles is unknown at scales less than a few tens of km. If cold-trapped volatiles are concentrated in limited areas, orbital techniques will not be sufficient to localize them. Only by exploring the surface can we determine the presence, abundance, composition and spatial distribution of cold-trapped volatiles. MVP will integrate three instruments: the Near Infrared and Visible Spectrometer Subsystem (NIRVSS), Neutron Spectrometer Subsystem (NSS), and a downward facing GroundCam camera on the KREX-2 rover to investigate the relationship between the distribution of volatiles (detected by NIRVSS and NSS) and soil crust variation (observed by GroundCam). Through this investigation, we will mature robotic in situ instruments and concepts of instrument operations, improve ground software tools for real time science, and carry out publishable research on the water cycle and its connection to geomorphology and mineralogy in desert environments.Our field site is the Mojave Desert, selected for its low, naturally occurring water abundance. The Mojave typically has on the order of 2-6% water (Webb 2002), making it a suitable analog for this field test. NIRVSS and NSS are specifically designed for detecting low water abundances. A lunar polar rover mission is unlike prior human or robotic missions and requires a new concept of operations. The rover must navigate 3-5 km of terrain and examine multiple sites in a very short time (Heldmann et al. 2012). Operational decisions must be made in real time, requiring constant situational awareness, fast data analysis and quick-turnaround decision support tools. This is unlike the daily command cycles and intermittent communications with Mars rovers, or rehearsed procedure execution of manned spaceflight. MVP will involve a small field team in the Mojave and a scientific and operational backroom team at NASA Ames. The operational and communications architectures between these teams will serve as a foundation for the development of decisional frameworks and operational concepts of future lunar rover missions.

Author: ANGELA STICKLE
POSTER

Missions (Including Commercial)

Illumination Simulations for Long Duration Landed Missions to the Lunar Poles

Recent missions to the Moon acquired global high-resolution topography data of the lunar surface. These data are of sufficient quality that they can be used to simulate illumination conditions on the lunar surface for any sun location with confidence and thus can be used to create detailed simulations of illumination conditions during future missions. We have developed a software tool, LunarShader, which precisely simulates lunar illumination conditions through the use of a fixed sun position and a gridded topographic image file. The output of the model is a second gridded image file that contains the percentage of sun available to each pixel. The simulation is run over a set period of time (e.g., the year from 10/22/2018 to 10/22/2019) with a constant time difference between each image (here, we are looking at 1-hr intervals). These illumination data can be used to derive parameters of interest for planning lunar lander or rover missions, including: longest period of continuous illumination, longest period of shadow, mean illumination, permanently shadowed regions, and earth-visibility maps. In this study, these data are used to identify areas of the lunar North Pole that could support a future mission continuously in sunlight. For a 30-m spatial resolution and a 1-hr time resolution, regions on the North Pole of the Moon (above 75° latitude) receiving a high percentage of average illumination over a one-year time period were identified. The three regions with the highest percent illumination are all illuminated for 75-90% of the year. The highest average illumination is 85.75% for a region on the edge of Whipple crater (on the edge of Peary crater). Using these data, we developed an algorithm to keep a potential landed rover constantly in sunlight assuming the rover could move at average rover speeds (e.g., 30-90m/hr). We track the percent sunlight at the simulated rover's current position, and if within two hours the current position will transition into shadow, the simulated rover will examine surrounding areas and move to a sunlit region. If more than one nearby pixel is sunlit, the rover will move to the nearest area with the longest period of continuous sunlight. This alleviates the need for large amounts of batteries and allows for a long-term landed mission powered solely by solar panels.

Author: JUERGEN THIEME
ORAL

Missions (Including Commercial)

X-ray spectroscopy with high spatial resolution – the SRX beamline at NSLS-II

X-ray spectromicroscopy is a very useful way of combining high spectral with high spatial resolution. The smallest structures visible in an X-ray microscope at present are below 10 nm size. X-ray microscopy is capable of imaging specimens directly, even in aqueous media; there is no need for fixation or staining. Due to the refractive index of matter being close to unity, clear images without scattering background are obtained even when studying thick and inhomogeneous samples. Therefore, X-ray microscopy images can be used for tomographic reconstructions of thick samples. By choosing the used X-ray energy appropriately, it is possible to perform spectromicroscopy studies. X-ray fluorescence can be used as a highly sensitive method to identify trace elements. Comprising, the combination of microscopy and spectroscopy enables studies of structures showing dimensions on the nanoscale, e.g. the composition of interplanetary dust particles, and is a powerful way for addressing key questions in many scientific areas. An electron storage ring, being an X-ray light source of extreme brightness, is the site of installation for an X-ray spectromicroscopy station. The National Synchrotron Light Source II promises to be the world's leading light source for such a station. Its source characteristics are ideally suited for experiments in need of coherence and provides an ideal platform for sub-μm focused beam instruments. The Sub-micrometer Resolution X-ray spectroscopy beamline (SRX) at NSLS-II has been developed specifically as an X-ray fluorescence analytical probe, allowing for the study of chemical and physical properties of complex systems even on trace elemental concentration levels. The scientific emphasis is the study of such systems with chemical heterogeneities at sub-μm and sub-100nm length scales. The beamline will provide X-ray spectroscopy capabilities in the energy range from 4.65keV to 23keV. SRX utilizes two sets of Kirkpatrick-Baez mirror optics for focusing, a high-flux setup that will deliver more than 10^13 phot/sec in a sub-μm spot and a high-resolution setup that will deliver a focal spot size of less than 100nm at a flux of approximately 10^11 phot/sec. The energy range covered will allow for X-ray spectroscopy experiments starting at the K-absorption edge of titanium and extending through the K-edge of rhodium, thus embracing a large section of the periodic table of elements. The photon flux SRX delivers in a sub-μm spot, ultimately combined with the use of new energy dispersive detectors like the MAIA, will open new possibilities for spectroscopic analysis of major and trace elements in natural and synthetic materials, X-ray fluorescence imaging of their distribution both in 2D and 3D, and concurrent μ-diffraction measurements. Coherent diffraction imaging experiments will be developed as well. Commissioning of the beamline will begin in fall 2014; first scientific experiments are planned for the beginning of 2015.

Author: DAVID WILLIAMS
POSTER

Missions (Including Commercial)

.Lunar Data Project/Lunar Data Node: Apollo Data Restoration Update

The Apollo Lunar Surface Experiments Packages (ALSEPs) on Apollo 12, 14, 15, 16, and 17 returned data from the lunar surface until September 1977. These long-term in-situ data, along with data from Apollo surface and orbital experiments, still comprise some of the best information on the Moon's environment. Much of these data were archived at the National Space Science Data Center (now the NASA Space Science Data Coordinated Archive, NSSDCA) in the 1970's and 1980's, but a large portion of the data were never submitted. The data that were archived were generally on microfilm and microfiche, or on magnetic tapes in obsolete formats, making them difficult to use today. And in many cases the documentation and other ancillary information (metadata) are insufficient to allow for proper scientific use of these data. We report on the efforts of the Lunar Data Project, to: 1) put the archived data into digital formats to make them more easily obtainable and readable; 2) search for and recover data which were never archived and bring them into the NSSDCA; and 3) compile the appropriate metadata to accompany these data sets. Data sets which are completed in this way are archived with the Planetary Data System (PDS) through the Lunar Data Node at the NSSDCA under the auspices of the PDS Geosciences Node.Nine lunar data sets have been fully restored and archived through PDS from the Apollo 12 and 15 Solar Wind Spectrometer, the Apollo 14 and 15 Cold Cathode Ion Gage, the Apollo 17 Traverse Gravimeter, and the Apollo 15 and 16 Soil Mechanics Penetrometer. A number of data sets have been restored and submitted for PDS review and are now in lien resolution: Apollo 14 and 15 Dust Detector, Apollo 15 and 17 Heat Flow, and the Apollo 15 and 16 X-Ray Spectrometer. We are currently in the process of restoring data from a large number of Apollo experiments, including the Apollo 17 Lunar Ejecta and Meteorites Experiment, the Apollo 11 and 12 Dust Detector Experiments, the Apollo 16 Active Seismic Experiment, the Apollo 17 Lunar Atmospheric Composition Experiment, the Apollo 14 Charged Particle Lunar Environment Experiment, the Apollo 14 and 15 Suprathermal Ion Detector Experiment, the Apollo 17 Infrared Radiometer, and the Apollo orbital and surface magnetometers.We are also working on new data sets as part of proposals funded by LASER, including the ALSEP ARCSAV (Telemetry) tapes, the ALSEP Housekeeping data, the Apollo 15 and 16 Mass Spectrometer data, the Apollo 17 Far-UV Spectrometer data, the Apollo 15, 16, and 17 Photography Indexes, the Apollo 17 Surface Electrical Properties Experiment, and the Apollo 14 and 15 Gamma-Ray Spectrometer. We continue to look for unarchived data and metadata from many experiments, including the Heat Flow, Lunar Ejecta and Meteorite, and Lunar Surface Gravimeter. This presentation will give an update of our efforts. The fully restored data sets are available online at the PDS Geosciences Node: http://geo.pds.nasa.gov/missions/apollo/index.htm

SSERVI-ESF14-205

Author: ROBERT WINGLEE

ORAL

Missions (Including Commercial)

Sample Return using High Velocity Penetrators

There have only been a few sample return missions since the start of the space age. Their limited number reflects their high cost, with the most recent missions taking only small surface samples. This paper reports results from the development of a high velocity (150-600 m/s) penetrator that is able to take a core sample down to a few meters, and requires simpler orbital maneuvers to reduce the mass and cost requirements of a sample return mission. The penetrator is able to survive the high velocity impact through innovations associated with energy absorbing material that support the sample return container. Material for the solar system object move through a central feed system. Extraction of the sample is via an attached tether system that is used to both reduce the Delta V of the impact and return the sample to main spacecraft. Examples of survivability through impacts in playa and in rocky material are presented along with an overall mission scenario.

Author: KRIS ZACNY

ORAL

Missions (Including Commercial)

IceBreaker Drill

One of the main goals of the Icebreaker Mission to Mars is to search for evidence of life on the planet. To enable the search, a sample of ground ice needs to be acquired and transferred into a life detection instrument. Samples need to be acquired from depths greater than approximately one meter; that is below the range of harmful radiation that reaches the surface of Mars. Since the 1990s, we have been developing drilling technologies for reaching below one meter depth on various planetary bodies, including Mars and the Moon. The drilling approaches included rotary, percussive, sonic, and ultrasonic. The most promising one was percussive and it was selected for the IceBreaker3. The IceBreaker3 drill is at TRL 5/6 and weighs approximately 10 kg.The IceBreaker3 drill captures cuttings rather than the core. This greatly simplifies sample handling and the drill itself. The sample is captured in a 'bite' approach that is after drilling a 10 cm interval, the drill is pulled out and sample transferred into an instrument via one of three methods . While the sample is being analyzed, the drill is in a safe position above the ground. To capture next sample, the drill is inserted into the same hole and after reaching hole bottom, captures next 10 cm sample. This method allows preservation of stratigraphy. The drill serves as a 'science' instrument as well. The telemetry can be used to assess strength of the formation and identify ice lenses. The bit temperature can be used to plot thermal gradient to 1 m depth, and potentially determine heat flow property of the planet. The drill could also be used on other planetary bodies, such as the Moon, for acquisition of dry or icy regolith for In Situ Resource Utilization (ISRU) missions.The IceBreaker videos can be watched here: https://www.youtube.com/watch?v=fTNPokiXa0E and https://www.youtube.com/watch?v=QE7aYUnAA9o

Author: GORDON CHIN

Radiation

ORAL

Determining the Magnitude of Neutron and Galactic Cosmic Ray (GCR) Fluxes at the Moon using the Lunar Exploration Neutron Detector (LEND) during the Historic Space-Age Era of High GCR Flux

The Lunar Reconnaissance Orbiter (LRO) was launched June 18, 2009 during an historic space age era of minimum solar activity. The lack of solar sunspot activity signaled a complex set of heliospheric phenomena that also gave rise to a period of unprecedentedly high Galactic Cosmic Ray (GCR) flux. These events coincided with the primary mission of the Lunar Exploration Neutron Detector (LEND), onboard LRO in a nominal 50-km circular orbit of the Moon . LEND measures the leakage flux of thermal, epi-thermal, and fast neutrons that escape from the lunar surface. Neutrons are produced within the top 1-2 meters of the regolith by spallation from the GCR flux. The energy spectrum and flux of the emergent neutron population is highly dependent on the incident flux of the GCR due to its influence on the depth of neutron production and total number of neutron-producing events.Methods to calculate the emergent neutron albedo population using Monte Carlo techniques rely on an estimate of the GCR flux and spectra calibrated at differing periods of solar activity. Estimating the actual GCR flux at the Moon during the LEND's initial period of operation requires a correction using a model-dependent heliospheric transport modulation parameter to adjust the GCR flux appropriate to this unique solar cycle. These corrections have inherent uncertainties depending on model details. Precisely determining the absolute neutron and GCR fluxes is especially important in understanding the emergent lunar neutrons measured by LEND and subsequently in estimating the hydrogen/water content inthe lunar regolith.Simultaneous measurements of the LEND detectors determine the absolute GCR and neutron flux levels: LEND is constructed with a set of neutron detectorsto meet differing purposes. Specifically there are two sets of detector systems that measure the flux of epithermal neutrons: a) the uncollimated Sensor for Epi-Thermal Neutrons (SETN) and b) the Collimated Sensor for Epi-Thermal Neutrons (CSETN). LEND SETN and CSETN observations form a complementary set of simultaneous measurements that determine the absolute scale of emergent lunar neutron flux in an unambiguous fashion and without the need for correcting to differing solar-cycle conditions. LEND measurements are combined with a detailedunderstanding of the sources of instrumental background, and the performance of CSETN and SETN. This straightforward estimation has been verified with detailed simulations of the LRO spacecraft and its influence on SETN and CSETN using the Geant4 Monte-Carlo framework developed at CERN.This comparison allows us to calculate a constant scale factor that determines the absolute flux of neutrons at the Moon and then subsequently to deduce the properscale of the GCR flux model without correction or use of the heliospheric modulation potential for this unique solar cycle minimum.

Author: JOHN COOPER

ORAL

Radiation

Space Weathering Investigations Enabled by Virtual Energetic Particle Observatory and the Space Physics Data Facility

The NASA Virtual Energetic Particle Observatory (VEPO) and Space Physics Data Facility (SPDF) collaborate on provision of data products and services of strong potential use for modeling of space weather and resultant surface weathering on inner and outer solar system objects, and for radiation hazard assessments related to robotic and future human exploration missions. The VEPO services are provided in direct collaboration with the DREAM2 team of SSERVI. Current VEPO services include intercomparison of differential flux spectra for protons, helium, and heavier ions from operational missions including the Advanced Composition Explorer (ACE), WIND, SOHO, and STEREO-A/B. Older mission data are also available for comparison from earlier epochs for Ulysses, IMP-8, Helios-1/2, Pioneer-10/11, and Voyager-1/2. As discussed, the differential flux spectra can be transformed with radiation transport models, e.g. GEANT, into depth dosage and surface sputtering profiles useful for modeling of space weathering effects and radiation hazards. Long term averages can be computed to simulate solar cycle effects. A further important application is to compare flux data from different sensors and spacecraft to check instrument calibrations.

Author: PATRICK GASDA

ORAL

Radiation

Laser Space Weathering of Carbon: What can we expect from NEO sample return?

Two upcoming missions, OSIRIS-REx and Hayabusa-2, plan to visit B- and C-type asteroids in order to return pristine samples of these asteroids. If these asteroids are indeed carbonaceous, then they may contain up to ~5% organic carbon, mainly in the form of macromolecular carbon (MMC). MMC in meteorites can be studied with Raman spectroscopy. Changes in its Raman spectral parameters correlate with the petrographic grade of the meteorite. But these petrographic studies are calibrated with internal pieces of meteorite samples, so the MMC seen in meteorites may not have experienced space weathering. Carbonaceous meteorites that contain space-exposed asteroid regoliths are uncommon in meteorite collections and it is uncertain if asteroid regolith samples we have are representative of asteroid regolith. Hence, it is important to determine the effects space weathering may have on the MMC and on its Raman spectrum. Laser pulse heating experiments that simulate the micrometeorite impact component of space weathering have been carried out in 30 s increments on uncompressed powders of pure graphite and a sample of Allende, which is a CV petrologic type 3 carbonaceous chondrite. Powders were contained within a glass sample cup. Pulse heating was done in vacuum (1_10-6 torr) with a 1064 nm Nd:YAG laser running at 20 Hz, a 6 ns pulse duration (30 mJ/pulse), and a 200 _m spot size. Raman spectra were collected on the each sample using a WITec alpha300 R confocal Raman microscope, with a 45.5 _W 532 nm continuous laser and a ~10 _m laser spot size.Preliminary results show that Raman spectra of the original graphite powder exhibit dramatic changes. The original pure graphite is modified to disordered graphite by 10 minutes (60,000 laser pulses), and further modified to glassy carbon (nanocrystalline 3-coordinate carbon) within 20 minutes (120,000 laser pulses). Vapor deposited on the side of the sample holder has a Raman spectrum consistent with amorphous carbon glass (3- and 4-coordinate carbon). Changes to the Raman spectrum for Allende are much more subtle than the graphite experiments and no amorphous carbon is detected as a vapor deposit. There is a much lower concentration of carbon in Allende compared to pure graphite, so the weathered MMC Raman signals might be below the detection limit. The majority of Allende is silicate minerals. It is possible that melt and vapor deposited silica rims may contain a few percent carbon, but TEM measurements are needed to confirm this hypothesis. TEM studies of the space-weathered graphite are needed to confirm the phase change from graphite to glassy carbon, to confirm the presence of amorphous carbon, and determine the carbon coordination number of these phases. TEM studies of Allende might show small amount of weathering of the MMC, which may exhibit a different carbon coordination number compared to the space-weathered graphite. Additional meteorite classes will be studied, such as type 2 CM (e.g. Murchison) and type 3.0 ordinary chondrites (e.g. Bishanpur).

SSERVI-ESF14-210

Author: NATHAN SCHWADRON

ORAL

Radiation

Understanding Tissue Equivalents Radiation Interactions in a Worsening Radiation Environment

The Sun and its solar wind are currently exhibiting extremely low densities and magnetic field strengths, representing states that have never been observed during the space age. As a result of the remarkably weak solar activity, we have also observed the highest fluxes of galactic cosmic rays in the space age, and relatively small solar energetic particle events. We examine the implications of these highly unusual solar conditions for human space exploration. The worsening radiation conditions in space motivate further validation of our understanding of the radiation interactions, particularly due to secondary populations behind shielding, at high altitude and in deep space. A new detector concept, Dose Spectra from Energetic Particles and Neutrons (DoSEN), combines two advanced complementary radiation detection concepts with fundamental advantages over traditional dosimetry. DoSEN not only measures the energy but also the charge distribution (including neutrons) of energetic particles that affect human (and robotic) health in a way not presently possible with current dosimeters. For heavy ions and protons, DoSEN provides a direct measurement of the Lineal Energy Transfer (LET) spectra behind shielding material. For LET measurements, DoSEN contains stacks of thin-thick Si detectors similar in design to those used for the Cosmic Ray Telescope for the Effects of Radiation (CRaTER). CRaTER is the first instrument of its kind to provide the needed ground truth measurements of LET spectra that provide the direct and critically-needed link between biological effectiveness to the radiation environment. With LET spectra, we can now directly break down the observed spectrum of radiation into its constituent heavy ion components and through biologically-based quality factors provide not only doses and dose-rates, but also dose-equivalents, associated rates and even organ doses. DoSEN also measures neutrons from 10-100 MeV, which requires enough sensitive mass to fully absorb recoil particles that the neutrons produce. The penetrating nature of the neutrons is offset by their intensity and sufficiently long exposure times, thus the constraining envelope dimension is the range of the recoil particles—typically protons in hydrogenous material. Because it is prohibitive to make a detector large enough to absorb the full energy of each neutron, the response of the instrument is broad, but still the task of measuring the spectrum and intensity in the featureless neutron spectrum is straightforward. Such technology has been in use for decades, but adapting it to the smallest, most efficient and lowest mass envelope is challenging. DoSEN develops the new concept of combining these independent measurements, and using the coincidence of LET measurements and neutron detection to significantly reduce backgrounds in each measurement. The background suppression through use of coincidence allows for significant reductions in size, mass, and power needed to provide measurements of dose, neutron dose, dose-equivalents, LET spectra, and organ doses. As we enter a new regime for the space environment due to drastic changes in solar behavior, the DoSEN concept lays a fundamental new groundwork for improving our understanding of the unique primary and secondary populations that cause biological damage.

Author: JULIE CASTILLO-ROGEZ
ORAL

Robotics

Decadal Survey and Strategic Knowledge Gap Science Goals with Next Generation Low Cost Small Platforms

Most of the key science priorities of the planetary science decadal survey rely on observations that involve sampling or close proximity observations of a variety of bodies. These observations address chemistry responsive to origin science and habitability as well as observational strategies for deep interior probing via internal or field geophysics. Increased interest in the reconnaissance of small bodies for Human exploration, planetary defense, and in situ resources calls for in situ chemistry and geophysics measurements as well as approaches to probe small body soil properties for geotechnical assessment. Major progress in the miniaturization of instruments and subsystems is opening the door to novel architectures for in situ observations and multi-site field measurements. High science return per dollar architectures may be approached via scalable and modular platforms to enable a range of science objectives. Following the footsteps of Earth-observing Cubesats, a number of recent concepts have been exploring the potential for Cubesats to return science grade observations at a variety of bodies, either as independent or as secondary platforms. Concepts so far cover multisite magnetic and gravity field sampling, atmospheric probing, high-resolution imaging, and strategic knowledge gap specific packages (imaging, dosimeter, dust analyzer, etc.) Low cost landers are also gaining momentum, starting with the MASCOT lander developed by the German space agency, the Hedgehog lander developed by Stanford and JPL under NASA's Center Innovation Fund, minimalistic lander concepts developed at JPL, as well as penetrators and biology inspired concepts. Key to the exploration with small platforms is the miniaturization of science grade instruments that retain high performance despite highly constrained resources and short lifetimes. Small instruments for a variety of applications are gaining maturity, especially instrumentation for geophysical probing. The development of techniques for sampling material in low gravity environment, such as laser-excited spectrometry decreases the need for mechanically heavy and power intensive sampling techniques. Algorithms for onboard data processing and triage allow increasing the science value per bit and can help select observation and sampling sites when conditions limit the pace of ground involvement. This presentation will review the state of the art in small instruments and science operations in the context of reconnaissance mission concepts for the Human exploration of near earth asteroids and Mars' moons and environment. Acknowledgements: Part of this work is being developed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. The Hedgehog project is supported by NASA's Center Innovation Fund.

Author: MARCO PAVONE
ORAL

Robotics

Optimizing Decadal And Precursor Science At Phobos With Spacecraft/Rover Hybrids

We present a mission architecture to address both high-priority science identified for Mars_ moons and strategic knowledge gaps for the future Human exploration in the Martian system. The basic architecture involves a mother spacecraft and one or several minimalistic in-situ mobility platforms, called spacecraft/rover hybrids, first studied under the 2011 NASA Innovative Advanced Concepts (NIAC) program.The mission aims at exploring the surface of Phobos in proximity to the Stickney crater. This region is of particular interest for several reasons. First, previous missions have identified spectral similarities between some terrains in the Stickney region and C-type asteroids, i.e., asteroids that are believed to be rich in water and organics and related to carbonaceous chondrites. Besides, this area displays a large complexity in terms of terrain properties, variations in regolith color, mass wasting, ejected blocks, etc., which makes it a particularly interesting exploration target. In order to explore these different terrains, one needs a mobility platform that can both achieve a spatial coverage of a few kms and access discrete and narrow areas through fine mobility. This is particularly difficult due to the very low gravity environment, which challenges traditional forms of mobility such as wheeled or legged platforms. In our mission architecture, this capability would be provided by the aforementioned hybrids, which are minimalistic platforms employing an innovative mobility mechanism and carrying a suite of instruments complementing those on the mother spacecraft (which would act as a communication relay to Earth and perform remote measurements). Specifically, a spacecraft/rover hybrid is a multi-faceted geometric solid that encloses three mutually orthogonal flywheels and is surrounded by external spikes. The combination of the actuation of the flywheels with the enclosure_s and spikes' geometry would enable controlled tumbles (for fine mobility) and hops (for large surface coverage). This mobility concept has been validated on a number of microgravity test beds at JPL and Stanford, and has been recently selected for further validation on NASA's parabolic aircraft flights. The current state of miniaturized instrumentation allows the accommodation of several geophysical instruments and one analytical instrument within the hybrids, which, in conjunction with a stereo camera and a dust analyzer on the mothership, could provide key information about the physical properties and composition of the surface. Accordingly, a fundamental aspect of this architecture is that the responsibility for primary science would be shared between the mothership and the hybrids. The mothership would provide broad area coverage, while the hybrids would zoom in on specific areas and conduct in-situ measurements.

SSERVI-ESF14-213

Author: TED ROUSH

POSTER

Robotics

Exploring in the Dark

In low light level environments (LLEs) on Earth, humans typically provide sufficient, if not excessive, illumination via abundant energy sources. Planetary surface rovers have extensively explored exclusively in the sunlight. However, robotic exploration in LLEs of interest to resource potential, e.g. permanently shadowed regions at lunar poles, or biologically protective environments, e.g. lava tubes and other caves, share a common characteristic; abundant energy is seldom, if at all, available. Anyone that has traveled in the dark is aware of how their perception of their surroundings is driven by their illumination source. We discuss the potential impact on science operations and understanding that occurs while operating a rover in LLEs.

Author: KRIS ZACNY

ORAL

Robotics

PlanetVac: Pneumatic Sample Acquisition and Delivery System for Asteroids

One of the hardest things to do in planetary exploration, but one of the most valuable, is to sample a planetary surface – gather planetary regolith – and then transfer it to a science instrument or sample return capsule. Current ways to do that, such as robotic arms, are costly and complex with lots of moving parts. PlanetVac, which stands for Planetary Vacuum, is a concept that effectively blows material up tubes using compressed gas provided from the pressurant tanks or dedicated tanks. The PlanetVac sampling devices is built into the lander legs to eliminate costly deployment from the lander deck to the ground. This technique can be used to feed regolith, including small rocks, to science instruments and/or feed it into sample return rockets on landers on Mars, asteroids, or the Moon. Because of the low pressures on all those bodies, the technique is extremely efficient; the efficiency is related to the ratio of the exit gas pressure to the ambient pressure (or vacuum).
To demonstrate this approach, PlanetVac lander with four legs and two sampling tubes has been designed, built, and tested. Testing has been performed in vacuum chamber and with two planetary simulants: Mars Mojave Simulant (MMS) and lunar regolith simulant JSC-1A. One sampling system was connected to an earth return rocket while the second sampling system was connected to a deck mounted instrument inlet port (clear box for easy viewing). Demonstrations included a drop from a height of ~50 cm onto the bed of regolith, deployment of sampling tubes, acquisition of regolith into an instrument (sample container) and the rocket, and the launch of the rocket. In all tests, approximately 20 grams of sample has been delivered to the regolith box and approximately 5 grams of regolith has been delivered into a rocket. The gas efficiency was calculated to be approximately 1000:1; that is 1 gram of gas lofted 1000 grams of regolith. PlanetVac video can be watched here: https://www.youtube.com/watch?v=DjJXvtQk6no

Author: JAMES BAUER
ORAL

Volatiles

NEOWISE Observations of Comets : CO/CO2 Gas Emission

NEOWISE is the planetary-funded mission that utilizes data from the Wide-Field Infrared Survey Explorer (WISE) spacecraft to detect and characterize moving objects. NEOWISE has provided a large statistical sampling of comets in various states of activity, containing a variety of types of comets. This data set provides a unique opportunity to discern the trends in their observable properties and compare the mean properties between classification schemes, and may provide a basis for understanding the differences between the underlying populations of comet subtypes. The WISE spacecraft discovered 22 new cometary bodies and observed over 160 comets during the prime mission (January 2010 through January 2011), yielding the largest sample of comets yet observed at thermal-IR wavelengths. This collection, obtained before the depletion of the cryogen at the end of September 2010, offers a diverse range of comet behavior including highly active and inactive bodies from both long period comet (LPC, orbital period > 200 years) and short period comet (SPC, period < 200 years) populations. In particular, our analysis characterizes the production rates and extent of the CO/CO2 gas species, basic volatiles of likely primordial origin that are most easily detected at these wavelengths. These primitive volatile species, which sublimate at faster rates than H2O when the comet is at larger distances from the Sun, may indicate the degree of processing a particular comet has undergone and how depleted their surfaces are of volatiles in general, including water. Comparison of the 4.6 micron band signal, containing significant signal from emission lines of these two gas species at 4.26 (CO2) and 4.67 (CO) microns, with the signal in the other 3 bands at 3.4, 12, and 22 microns, facilitates separation of the gas from the nucleus and dust flux contributions. In the comets discovered by WISE, about 1/3rd showed significant 4.6 micron band flux excess, including 2 that are NEOs, and one that approaches within 4 lunar distances from the Earth's orbit. In December of 2013, the WISE spacecraft was re-activated to continue its search for NEOs under the NEOWISE program. As the NEOWISE mission continues to take images, the number of active comets observed by WISE grows. As of April 2014, nearly a dozen comets have been observed in the restart of NEOWISE, including the newly discovered Halley-Family comet C/2014 C3 (NEOWISE). Though these images are only in the 3.4 and 4.6 micron bands, NEOWISE has been able to provide constraints on gas production for several of these comets. We will discuss how the results of the prime mission cometary data are being utilized to extract more accurate CO/CO2 production rates from the 2-band NEOWISE data, and what the sample of 160 comets from the prime mission indicates regarding cometary composition in the LPC and SPC cometary populations.This work was supported by NEOWISE, which is a project of the Jet Propulsion Laboratory/California Institute of Technology, funded by the Planetary Science Division of NASA.

Author: SANDRA BLEVINS
POSTER

Volatiles

Snow line localization in classical protoplanetary disks

Protoplanetary disks are volatile-rich environments capable of producing the essential conditions that make planet formation viable. Establishing a molecular inventory of dominant volatile species in the planet-forming zones surrounding young, solar-type stars elevates our understanding of the chemistry involved with planet formation, composition and disk evolution. Specifically we wish to compare these young systems to the solar nebula so that we may better understand the initial conditions driving planet formation and explore the uniqueness of our solar system and its distribution of water. For this study we measure the water vapor content and determine the location of the condensation front, or snow line, for four classical disks selected for the strong water emission present in their mid-infrared spectra. To accomplish this we combine deep Herschel PACS observations with high resolution Spitzer IRS spectra to create molecular maps comprised of water lines with excitation temperatures that trace the disks' surfaces from ~ 1-100 AU. We use two-dimensional, axisymmetric radiative transfer modeling to retrieve the disks' dust structures and the RADLite raytracer to render model spectra for each disk. A simple step function is used to define the abundance structure and the model spectra are fit to the observed water lines. Fresh results will be discussed, including the inner disk chemical content, snow line radius and fractional water vapor abundances for the young, solar analog RNO 90.

Author: NANCY CHABOT

Volatiles

ORAL

Inner Solar System Volatiles: Insights from Images of Mercury's Polar Deposits

Earth-based radar astronomers first discovered evidence for water ice near Mercury's poles, and the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission has acquired additional evidence. These include maps of areas of permanent shadow, active measurements of high and low surface reflectance, thermal modeling consistent with the long-term retention of water ice, and the detection of hydrogen-rich material. More recently, using light scattered from illuminated crater walls, MESSENGER's Mercury Dual Imaging System (MDIS) captured images of permanently shadowed and likely ice-bearing crater floors. These images reveal extensive, spatially continuous regions with distinctive reflectance properties. Within Prokofiev crater, a location where surface water ice is thermally stable, both the sunlit and permanently shadowed areas exhibit a similar cratered texture, but the shadowed area has a uniformly higher reflectance, suggesting the emplacement of water ice on the surface after the formation of even small craters on Prokofiev's floor. In areas where water ice is stable only in the near surface, and where a surficial layer of organic-rich volatile material has been predicted, the images reveal regions with uniformly lower reflectance that extend to the edges of the shadowed areas and terminate with sharp boundaries. The sharp boundaries indicate that the volatile deposits at Mercury's poles are geologically young, relative to the timescale for lateral impact mixing. The images of the polar deposits on Mercury contrast with images acquired by a similar approach for shadowed craters on the Moon. Though laser reflectance measurements have yielded higher reflectance values for Shackleton crater at the lunar south pole, indicative of modest amounts of water frost or a reduction in the effectiveness of space weathering, imaging of permanently shadowed lunar craters has not revealed surfaces with anomalously high- or low-reflectance similar to those found on Mercury. Understanding the different volatile inventories in the polar regions of Mercury and the Moon would provide insights into the nature and delivery of volatiles in the inner Solar System. One possibility for the contrasting observations is that Mercury's polar deposits were recently delivered to the planet by one or several large events. Such a scenario would suggest that the Moon also may have hosted more extensive polar deposits in its past, but that most of the lunar deposits have subsequently been lost or sequestered beneath the surface. Alternatively, the fresh appearance of Mercury's polar deposits may suggest an ongoing process that is able to restore the deposits even at present. The total amount of ice currently at Mercury's poles is substantial, with estimates of ~10^16-10^18g, the high end of which is comparable to the volume of Lake Ontario. If delivered by a single comet, the estimated comet diameter is ~8-40 km. If Mercury's current polar volatile inventory is the product of the most recent portion of a longer process, then a considerable mass of volatiles may have been delivered to the inner Solar System throughout its history.

SSERVI-ESF14-218

Author: DAVID GLENAR

ORAL

Volatiles

Influence of Faint Light Sources on the Moon's Permanently Shadowed Regions

Light from numerous sources is incident on the surface within permanently shadowed regions (PSRs) near the lunar poles that are never directly exposed to sunlight. In this study we collate predictions for faint light sources that cover a broad range of wavelengths from the infrared to the far-UV, and consider their potential importance for the conditions within PSRs, which could have implications for the stability of volatiles and the suitability of the Moon as a platform for astronomical observatories. We consider the sources of incident light within a typical near-polar PSR from: (i) direct and scattered Earthshine, (ii) zodiacal light created by sunlight scattered from dust in the inner solar system; (ii) Lyman-alpha resonantly scattered by interplanetary hydrogen; (iii) the diffuse broadband galactic background; (iv) bright stellar sources; (v) emission lines from exospheric species that vary in intensity depending on the space environment at the Moon, which are typically dominated by sodium and potassium; and (vi) sunlight scattered by exospheric dust. For the latter, we consider dust in the lunar exosphere created by several processes, including possible naturally occurring transport phenomena, as well as dust agitated by exploration and in-situ resource utilization (ISRU) activities.

Author: JAMES HEAD, III

Volatiles

ORAL

Lunar Regional Pyroclastic Deposits: Evidence for Eruption from Dikes Emplaced into the Near-Surface Crust

Lunar pyroclastic deposits have several modes of occurrence; smaller, more isolated deposits suggest several modes of emplacement related to dike and sill emplacement, including strombolian, hawaiian, and vulcanian activity. The mode of emplacement of largest pyroclastic deposits (>1000 km2) has been less clear; for the Aristarchus Plateau deposits, very high effusion rate eruptions leading to sinuous rilles and associated pyroclastic emplacement have been implicated. A candidate modes of emplacement comes from analysis of the Orientale dark ring, a 154km diameter pyroclastic deposit that emanates from a linear depression interpreted to be a remnant elongated vent at the top of a dike; a wide dike stalled just below the surface, and the low-pressure environment led to gas buildup along the dike top, leading to eruption of an Io-like pyroclastic plume to produce the dark pyroclastic ring. Analysis of ascent and eruption of magma shows that the low-pressure environment associated with dike tip propagation could enhance formation of volatiles during dike ascent so that the dike arrives at the surface with the dike top already saturated with magmatic foam, and not requiring secondary buildup. Could this mechanism, arrival of volatile magmatic foam-laden dikes to the shallow subsurface, perhaps combined with further shallow crustal gas formation subsequent to stalling, lead to penetration of foams to the surface and eruption of magmatic foams to produce regional pyroclastic deposits? In these cases, the low pressure always present in the propagating dike tip means that as dikes approach the surface their upper tips will consist of a cavity containing gas underlain by a region where gas bubbles concentrate into a foam. If the dike fails to break through to the surface, gas bubbles migrate up through the foam to increase the size of, and pressure in, the gas cavity. Additional foam is generated beneath the gas cavity if the dike is wide enough to allow convection to occur because this brings magma from depth to shallow enough levels for additional pressure-dependent gas release. The Orientale example showed that these processes acting in a ~500m-wide dike produced an ~25-fold gas concentration leading to an explosive eruption emplacing a ~150km diameter circular pyroclastic deposit. A generic example of this process would involve a 100 km long linear rille graben induced by a 300 m-wide dike; magmatic foam would occupy the upper ~ 8 km of the dike where the pressure was less than 40MPa. If the foam evolved the gas would ultimately represent ~5 mass % or ~50000ppm. Foam release would produce an eruption speed of 487 m s-1 ejecting pyroclasts to ~147km. If this magma were deposited as pyroclasts over an area of 100 km (the rille length) x ~ 147km (the maximum range) with a bulk density on landing of 2000kg m-3, the resulting deposit thickness would be ~5m. We infer that essentially all of the observed dark mantle regional pyroclastic deposits on the Moon can be explained by minor variations on this scenario.

Author: AMANDA HENDRIX

ORAL

Volatiles

REGIONAL VARIATIONS IN FUV LUNAR SIGNATURES

The Lunar Reconnaissance Orbiter (LRO) is currently in orbit at the Moon. The Lyman Alpha Mapping Project (LAMP) onboard LRO has been making measurements of the lunar nightside, dayside and atmosphere since September 2009. We report here on recent work analyzing LAMP dayside data, focusing on weathering and hydration effects in mature vs. immature terrains, including swirls. The LAMP instrument [1] is a photon-counting imaging spectrograph. The entire passband is 57–196 nm, in the far-UV (FUV) spectral region. For dayside measurements, the instrument is operated in “pinhole” mode, with the aperture reduced by a factor of 736. The instrument was usually nadir-pointed in LRO’s characteristic 50-km lunar orbit of the prime mission and provided ~500 m resolution. Approximately once per month LRO flies over any particular region; and although LAMP halts acquistion of dayside data when at high phase angles, there are numerous sets of spectra of each region at differing geometries; the emission angle is small while the incidence angle is larger and varies depending on the beta angle of the orbit. To determine the lunar FUV reflectance, we divide the LAMP data from each latitude bin by the full-disk solar spectrum from SORCE SOLSTICE [2], taken for the day of each observation and convolved to agree with the LAMP resolution and line spread function. The FUV hosts a strong H2O absorption edge near 165 nm, allowing LAMP to study hydration on the Moon [3]. Past analyses of LAMP dayside data (e.g. [3]) have shown that the measurement of spectral slopes in the 164-173 nm range is an indicator of hydration, while spectral slopes in the 175-190 nm region are insensitive to hydration but good indicators of weathering and composition.Here we use this spectral slope information to study hydration and weathering effects in swirls regions (Reiner Gamma, Mare Ingenii, Gerasimovich, Descartes highlands) and in immature regions (e.g. after [4]).References: [1] Gladstone, G. R. et al. (2010) SSR, 150, 161-181. [2] McClintock et al. (2000) Proc. SPIE Earth Obs. Syst., 4135, 225–234. [3] Hendrix et al. (2012) JGR, 117, E12001, doi:10.1029/2012JE004252. [4] Lucey, P. G. et al. (2000) JGR, 105, 20377.

Author: CHARLES HIBBITTS

ORAL

Volatiles

Relevance of UV Reflectance Spectroscopy to Inferring the Compositions of the Moon and Asteroids

Reflectance spectroscopy in the vacuum ultraviolet through visible wavelengths is sensitive to the abundance of opaque materials, especially transition metal cations. Reflectance data were collected for nine glass samples, alumina, anorthite, and water frost. The glass samples are compositionally similar to those in the regolith on the Moon and Mercury, with the notable caveat that some of the iron is oxidized. It is known that the oxidation state of iron affects the visible-NIR region of the spectrum and may affect the UV as well [1,2,3]. Total iron in the glasses varies from 0 to ~21% when expressed as total FeO, with the fraction of iron as Fe3+ varying from 0 to almost 80%, but not correlated to total iron abundance. The abundances of other transition elements are small, with TiO2 being the most abundant and varying from 0 to about 1.5%. TiO2 con-tent does not correlate with FeO. About 100 mg of glass samples ground to talc-like consistency (grain sizes <1 _m) was placed in a copper sample holder mounted in a vacuum chamber. Measurements were obtained with a McPherson 302 vacuum monochrometer with a deuterium source and a PMT detector mounted in front of a MgF2 window coated with a scintillation material. Each sample was maintained at room temperature and ~10-7–10-8 torr. Each sample was heated to ~ 80C overnight at this pressure to remove all adsorbed molecular water. Thus, only hydroxyl, either internal or chemisorbed, remained present. The water ice spectrum is consistent with literature values for fine-grained frost [e.g. 4]. Both water ice and alumna are similar, staying bright into the VUV where single strong absorption feature occurs at ~200 nm for alumina and ~160 nm for water frost. Silicates behave differently due to the presence of cation and transition elements in their compositions (1,2). Both iron abundance and valence state control the position of the absorption near 300 nm, and are responsible for the NUV slope that has been often reported for these materials (3). As iron concentration decreases, the NUV drop off near 400 nm shifts to shorter wavelengths and the center of the absorption band also shifts shortward. The effects of iron oxidation in the VUV are small compared to the effects of iron abundance. The position of the absorption band near 300 nm and the brightness of the VUV continuum near 225 nm are both sensitive to changes of a percent or less in iron abundance and may provide a an additional means for quantifying the iron abundance of low iron minerals and glasses. Acknowledgement: This work has been supported by NASA grants: NLSI NNA09DB31A, SSERVI NNA14AB02A, PGG NNX10AI58 and LASER NNX11AO54G.References: [1] Sigel, G.H., (1974), J. Non-crystalline Solids, 13, 372-398. [2] Tippins, H.H., (1970), Phys. Rev. B, 1,1, 126-135. [3 Pieters, C.M & Englert, P.A., (1993), Univ. Cambridge Press. [4] Hendrix, A.R. and C.J. Hansen, (2008), Icarus, 193, 323-333

Author: SHUAI LI

Volatiles

ORAL

Quantitative mapping of hydration in lunar pyroclastic deposits and implications for lunar volcanic processes

Lunar pyroclastic deposits represent early volcanic processes on the Moon capable of informing us of volatiles and eruption processes. Mapping of lunar surface hydration (H2O/OH) using M3 spectral reflectance data, corrected for thermal emission effects, shows that pyroclastic deposits exhibit much higher hydration levels than surrounding terrains. We have examined eleven large pyroclastic deposits (> 1000 km2) between 30° N and 30° S to assess detailed variations in hydration level and possible links to morphology and eruptive processes. These eleven deposits can be classified into three groups based on their average hydration levels. Pyroclastic deposits at Aristarchus, Sulpicius Gallus, and Humorum exhibit areally extensive high abundances of hydration (e.g., < 500 ppm on average), whereas Rima Bode, Montes Harbinger, and Moscoviense exhibit moderately high abundances of hydration (< 200 ppm on average). Taurus Littrow, Montes Carpatus, Vaporum and Nectaris have lower hydration levels (< 100 ppm on average) and Aestuum is an outlier, showing no detectable hydration absorptions in M3 data. Locations with the highest hydration levels correspond to dark, smooth regions in LROC WAC and earth-based S band RADAR CPR data, consistent with previous observations of lunar pyroclastics. In addition, average hydration content in the pyroclastics is linearly correlated with the spatial extent (area) of each deposit. If the hydration signature in these deposits represents volatiles (water) from the lunar interior, as opposed to solar wind implantation, then these detections provide important information on the volatile content of magma sources and constraints on degassing during eruption events. The different levels of hydration that we observe might indicate heterogeneity in volatile content of magma sources, different cooling rates, or different degrees of degassing. The lack of detectable hydration at Aestuum may be due to water-poor magmas or significant loss of volatiles during eruption and emplacement, and this deposit is known to be associated with distinct (spinel-bearing) mineralogies. The LROC NAC images at these large pyroclastic deposits show that the hydration abundances might be controlled by the thickness of glass-rich layers and/or the purity of the volcanic glass in the deposits. To understand the linear trend between the pyroclastic hydration level and areal extent we will also estimate the thickness of each pyroclastic deposit to provide an estimate on the volume of pyroclastic material. These volume estimates can be used as inputs for volcanic eruption models to calculate the required volatile content (H2O) to account for the observed size of each deposit, which in turn can be compared to our observed hydration levels from M3 data. Pyroclastic hydration can also be complicated by loss via diffusion after deposition, thus we also explore a post-emplacement diffusion model for lunar pyroclastics to understand the retention potential of water in volcanic glass at the lunar surface over geologic timescales.

Author: TIMOTHY LIVENGOOD
POSTER

Volatiles

Neutron Remote-Sensing at the Moon: Modeling the Empirical Variation with Altitude of Neutron Flux for the Lunar Exploration Neutron Detector (LEND)

The Lunar Exploration Neutron Detector (LEND) instrument on the Lunar Reconnaissance Orbiter (LRO) employs a collimator to improve the spatial resolution for neutron remote-sensing of hydrogen-rich volatile deposits on the Moon, with the primary goal of mapping deposits of water at the Moon's cold high latitudes. The collimator reduces the flux of lunar neutrons reaching the detector element from off-nadir directions so that neutrons reaching the detector through the narrow acceptance angle of the collimator opening contribute the primary signal. Verifying the component of epithermal neutrons that is detected in collimation is essential to estimating the actual concen-tration of water stored in localized deposits.

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Author: TIMOTHY LIVENGOOD

ORAL

Volatiles

Evidence for Diurnally Varying Hydration at the Moon's Equator from the Lunar Exploration Neutron Detector (LEND)

We detect hydrogen-bearing volatiles, most likely water and hydroxyl, concentrated near the Moon's dawn terminator by an active daily cycle of surface hydration and dehydration. This represents a potential volatile resource for in situ resource utilization (ISRU) that is distilled by natural processes and thus may be accessible at minimal energy cost. Measurements by the Lunar Exploration Neutron Detector (LEND) on the polar-orbiting Lunar Reconnaissance Orbiter (LRO) spacecraft detect hydrogen in the regolith through the localized suppression of epithermal neutron flux from the Moon's surface. At low latitude, the greatest flux suppression is found at dawn, with the least suppression and least hydrogenation in the lunar afternoon. This non-uniform and asymmetric distribution can persist only if a population of hydrogen-bearing volatiles is mobile across the sunlit lunar sur-face in the morning sector with an average horizontal velocity of 4.3 m/s in the anti-sunward direction, enabling the detected hydrogen to remain fixed with respect to the Sun while the Moon rotates.

Author: RICHARD MILLER
ORAL

Volatiles

New Insights Into the Polar Depth Distribution of Hydrogen at the Lunar Poles

We report new results on the depth distribution of enhanced hydrogen abundances at the Moon's North and South polar regions. The spatial distributions of hydrogen burial depth at both lunar poles have been estimated using a recent reanalysis of the epithermal and fast neutron datasets from NASA's Lunar Prospector mission, proven likelihood-based statistical analysis techniques, and comprehensive Monte Carlo simulations. Polar burial distributions provide additional insight into the processes relevant for lunar volatile deposits including burial, migration/mobility, and potentially their origin. Additional work includes comparisons with insolation, topographical, and temperature spatial distributions.

Author: WES PATTERSON
ORAL

Volatiles

Mini-RF Bistatic Observations of Cabeus Crater

The Mini-RF instrument aboard NASA's Lunar Reconnaissance Orbiter (LRO) is currently acquiring bistatic radar data of the lunar surface in an effort to understand the scattering properties of lunar terrains as a function of bistatic (phase) angle. Previous work, at optical wavelengths, has demonstrated that the material properties of lunar regolith can be sensitive to variations in phase angle. This sensitivity gives rise to the lunar opposition effect and likely involves contributions from shadow hiding at low phase angles and coherent backscatter near zero phase. Mini-RF bistatic data of lunar materials indicate that such behavior can also be observed for lunar materials at the wavelength scale of an S-band radar (12.6 cm). Radar observations of planetary surfaces provide important information on the structure (i.e., roughness) and dielectric properties of surface and buried materials. These data can be acquired using a monostatic architecture, where a single antenna serves as the signal transmitter and receiver, or they can be acquired using a bistatic architecture, where a signal is transmitted from one location and received at another. The former provides information on the scattering properties of a target surface at zero phase. The latter provides the same information but over a variety of phase angles. NASA's Mini-RF instrument on LRO and the Arecibo Observatory in Puerto Rico are currently operating in a bistatic architecture. This architecture maintains the hybrid dual-polarimetric nature of the Mini-RF instrument and, therefore, allows for the calculation of the Stokes parameters that characterize the backscattered signal.Circular Polarization Ratio (CPR) information is commonly used in analyses of planetary radar data, and is a representation of surface roughness at the wavelength scale of the radar (i.e., surfaces that are smoother at the wavelength scale will have lower CPR values and surfaces that are rougher will have higher CPR values). High CPR values can also serve as an indicator of the presence of water ice.Bistatic data for the south polar crater Cabeus has been acquired on four occasions and these data cover a phase angle range of 0° to 18°. When viewed at near zero phase, the floor of Cabeus crater shows an enhancement in CPR with respect to surrounding materials. This is not apparent in data acquired of Cabeus crater when Mini-RF operated in a monostatic mode. Further, when viewed at phase angles of several degrees, the floor of Cabeus crater shows a suppression of CPR with respect to surrounding materials. This scattering behavior for the floor of Cabeus crater indicates a clear opposition effect at low phase angles that is consistent with the presence of water ice. We suspect that the difference in the scattering behavior observed with a monostatic architecture is related to the grazing incidence (~85°) at which the region is viewed by Mini-RF when operating in a bistatic mode. This would suggest that the water ice observed would need to be confined to a relatively thin layer, near the surface.

Author: ANDREW RIVKIN

POSTER

Volatiles

Spectral Characterization and Mathematical Removal of Adsorbed Water

Water and OH have strong absorptions in the 3-μm spectral region. However, the exact band centers shift with type of water/OH (adsorbed vs. structural, for instance) and with host material. The details of these relationships are poorly-known, primarily due to a dearth of measurements under appropriate conditions.Much of the motivation for these measurements have come from spacecraft observations in which OH/H2O absorption features in reflectance spectra of airless bodies have been unexpectedly found in surfaces previously thought to be ‘dry’ However, most asteroidal data in the 3-μm region has been obtained by ground-based telescopes, and because of very low transmission through the Earth's atmosphere, the 2.5-2.85 μm spectral region is typically omitted from published spectra, often confounding the detection of water/OH bands. While the carbonaceous chondrite and their parent asteroids have broad enough absorptions to be detected at wavelengths greater than the atmospheric "water gap" the detection of small amounts of OH like what we see on the Vesta and may see on non-carbonaceous NEAs is much more dependent upon proper modeling and calibration without the 2.5-2.85 μm region.Most laboratory spectra available for meteorites and planetary materials have been obtained under ambient atmospheric conditions. While they are well-suited for the 0.3-2.5 μm region where work on silicate compositions is done, they are plagued by adsorbed terrestrial water and show deep bands in the 3-μm region. With data from the Rosetta flyby of Lutetia available in the PDS (and anticipating future data from Dawn and the Japanese AKARI spacecraft), understanding the spectral behavior of planetary materials, including nominally anhydrous minerals that may have small amounts of water/OH affecting this wavelength region will be critical to our compositional interpretations. As part of the VORTICES team, we are pursuing a set of laboratory experiments and spectral modeling tasks to measure "truly" anhydrous materials and quantify the spectral shapes of adsorbed water in varying conditions, with the ultimate goals of mathematically removing the signature of adsorbed water from the wealth of available RELAB data and greatly expanding the number of endmembers available for mixture modeling of asteroidal and planetary surfaces. We will discuss our plans for this project and share our progress to date.

Author: KATHARINE ROBINSON

ORAL

Volatiles

Varied H concentration and isotopic composition in the Lunar Interior

Water from the lunar interior has been measured in olivine-hosted melt inclusions, ferroan anorthosite plagioclase, residual glass in a KREEP basalt, and apatite grains from all other major lunar rock types (mare basalts, alkali suite, Mg-suite).The common goal of these measurements is two-fold: to constrain the water content of the bulk Moon, and to determine the source(s) of the Moon's water via hydrogen isotopic ratios. Estimating the pre-eruptive water content of the parental magma from glasses and melt inclusions is fairly straightforward, and it was initially thought that similar estimates could be made using OH abundances in apatite. It has recently been shown that volatile partitioning into apatite is more complex than previously thought, invalidating estimates of parental melt water content from apatite. However, apatite data is still a useful recorder of D/H ratios and relative water contents might be discernible among different rock types. Analysis of the picritic glass beads and melt inclusions showed that they originated from a magma with ~1000 ppm H2O. The source region for that magma would have contained 100 ppm, assuming ~10% partial melting to form the pyroclastic magmas. In contrast, our measurements of residual quenched glass in KREEP basalt fragments in 15358 contain 58-95 ppm H2O. Based on the modal abundances of the glass and accounting for H loss, the initial melt would have contained ~100 ppm H2O. The KREEP source would have thus contained ~10 ppm, an order of magnitude less than the picritic magmas. These calculations are somewhat rough, but indicate that there are at least two possible water reservoirs in the lunar interior.Water data from lunar apatite also indicates multiple reservoirs in the lunar interior. Water content of apatite in the major rock suites varies by 10-50x and seems to be related to rock type. KREEP-rich samples have the driest apatite, while mare basalt apatite is more water-rich. Additionally, the delta-D values of apatite vary widely. Elevated delta-D in mare basalts are almost certainly caused by H loss from lava flows, but some evolved, intrusive rocks also appear enriched in D (+200 to +500 permil). However, there are some samples that fall in the range of the terrestrial upper mantle (-140 to +60 permil D). Our measurements of apatite in quartz monzogabbro 15404, 55 have the lowest delta-D (-500) values reported from the Moon so far, indicating a third, low D source inside the Moon (Robinson et al. 2014 LPSC).Varied water concentrations and delta-D in the lunar interior probably reflect a combination of processes involved in lunar formation, primary differentiation in the magma ocean, secondary magmatism, and addition of material to the Moon after accretion. Which process(es) dominated is far from clear. The first step in increasing our understanding of water distribution in the Moon is to pin down its variability in all rock types and relate that to other important parameters, such as the abundances of highly volatile elements.

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ORAL

Volatiles

Evolution of Lunar ice stability

The polar regions of the Moon and Mercury have similar permanently shadowed environments, potentially capable of harboring ice. However, this has not always been the case for the Moon. Roughly 3±1 Gya, when the Moon is believed to have resided at approximately half of its current semimajor axis, lunar obliquities have been calculated to have reached as high as 77o (Goldreich et al. 1969; Ward, 1975; Wisdom and Touma, 1994; Siegler et al., 2011) This is due to a dissipation driven spin orbit coupling known as a Cassini State. Combined with the modeled orbital inclination for this time period, this left the lunar poles with a maximum solar illumination angle (here termed solar declination) of approximately 83o (Siegler et al. 2011). Lunar polar cold traps did not exist. Since that era lunar obliquity has secularly decreased, creating environments over approximately the last 1-1.5 Gyr (assuming near current recession rates) where water ice, if delivered to the Moon, should be stable.   In analogy to Mercury, where evidence points to nearly pure ice deposits likely deposited by a large cometary impact within the last several 10's of Mys (Crider and Killen, 2005), we would expect similar thermal environments on the evolving Moon to also retain relatively pure water ice for 10's to 100's of Mys. Though evidence points to a lack of Mercury-like pure ice deposits on the Moon (Campbell et al, 2006; More refs), this analogy makes it difficult to explain how all ice from of any similar impact over the past 1.5 Gyr could be lost. Essentially, to explain the paucity of ice in locations where it would be stable in the current thermal environment, one must claim that no comet similar to the one(s) which struck Mercury (assumed in the past few 10's on Myr) has struck the Moon in several hundred Myrs or longer.   One hypothesis to explain this discrepancy might be that such a cometary impact occurred not in today's lunar thermal environment, but a past one. If ice were delivered during a past epoch, the distribution of ground ice would be dictated not by present day temperatures, but rather by these ancient temperatures. This ancient ice, buried and mixed into the regolith by impact gardening. In this paper, we attempt to recreate the thermal environments for past lunar orbital configurations to characterize the history of lunar environments capable of harboring ice. We will develop models of ice mobility and degradation to examine likely fossil remains of past ice delivery (e.g. a comet impact) that could be observed on the present moon. We then compare this to interpreted geographical distribution of lunar ground ice from existing data sets.

Author: DOUGLAS STANDART

POSTER

Volatiles

Magmatic Lunar Hydroxly and Water: Redefining the KREEP Terrane Boundary

Early in the evolution of the Moon, towards the late stages of differentiation of the early lunar magma ocean, a relatively thin layer of melt would have remained and been enriched with thorium, water, hydroxyl, and other incompatible materials as a result of fractional crystallization of the lunar crust and mantle. This layer is known as KREEP (potassium, rare earth elements, phosphorus). Lunar crust that shows high concentrations of thorium and hydroxyl/water may indicate interaction with the KREEP layer. Using results from the Lunar Prospector Gamma Ray Spectrometer (LP-GRS), we selected thorium anomalies on the Moon in an effort to detect KREEP-rich or material using hyperspectral imagery. Four sites were chosen: Lassell Crater (15 S, 8 W), Hansteen Alpha (15 S, 50 W), Gruithuisen Domes (36 N, 40 W), and the Compton-Belkovich Thorium Anomaly (61 N, 100 E). Three of these sites are non-mare volcanic features within the Procellarum KREEP Terrane (PKT), the area on the lunar nearside which has a KREEP signature, while Compton-Belkovich is located on the lunar farside. The Moon Mineralogy Mapper (M3) hyperspectral imager was used to analyze the composition of these locations. The reflectance spectra gathered from these sites all show pronounced absorptions at ~2.8 microns, indicating the presence of hydroxyl/water. Maps of the 2.8-micron absorption show concentric patterns centered on these sites with the deepest absorptions at their centers. Digital elevation models and high-resolution imagery from the Lunar Reconnaissance Orbiter-Near Angle Camera (LRO-NAC) show that many of the 2.8-micron absorption maxima are associated with morphologies consistent with volcanic domes or vents. This association suggests that the volcanic features are associated with potential sources of magmatic volatiles and were the sites degassing those volatiles. In order to measure the concentration of hydroxyl/water associated with the 2.8-micron absorptions, we measure the area of a Gaussian curve fit to the absorption spectra. The area of the Gaussian curve, an assumed particle size of 45 microns, the density (3.0 g cm-3), and an integrated molar absorption coefficient are parameters used to determine the concentration of hydroxyl/water creating the absorption. To ensure that these absorption features are the result of KREEP-related water that is intrinsic to the Moon, and are not associated with solar wind implanted water, we compare available M3 images from different optical periods in the lunar day. Whereas the concentration of implanted water should vary on a diurnal basis as it migrates through the lunar regolith and exosphere, the nearside volcanic features show consistent 2.8-micron absorptions throughout the lunar day, a behavior consistent with intrinsic water. A magmatic water source would support the hypothesis that the lunar interior is more hydrous than previously thought; and it suggests that KREEP may underlie the far side highlands near CBTA and possibly other areas outside PKT.

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ORAL

Volatiles

Simulations of the thermal and plasma environment within lunar pits and lava tubes: could cryogenic regions trap ions from the solar wind?

Observed lunar holes and hypothesized lava tubes have been identified as possible targets for human exploration because they provide at least partial shelter from solar wind, radiation, and extreme heat variations. In this work we begin to characterize the full thermal cycle and plasma particle flow within an idealized lunar pit including a subsurface lava tube. Finite-difference heat transport simulations show development of a quasi-steady lunar heating cycle over thousands of lunar days, and plasma treecode simulations are used to model daily surface charging, photoemission, and ion flow into the pit. Interestingly, preliminary simulations of a 50 m-wide and 50 m-deep pit show that ions flow directly onto the hot, illuminated regions of the pit at times around local noon when the solar wind flow and solar radiation are close to vertical. The solar wind could thus provide a daily source of hydrogen and other ions that is quickly sublimated, with some fraction hopping laterally into adjacent lava tubes where it could remain cryogenically trapped.